Sorbent Injection for Small ESP Mercury Control in Low Sulfur Eastern Bituminous Coal Flue Gas

Quarterly Technical Progress Report
April 1 – June 30, 2004

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Disclaimer

Abstract

This document summarizes progress on Cooperative Agreement DE-FC26-03NT41987, “Sorbent Injection for Small ESP Mercury Control in Low Sulfur Eastern Bituminous Coal Flue Gas,” during the time-period April 1, 2004 through June 30, 2004. The objective of this project is to demonstrate the ability of various activated carbon sorbents to remove mercury from coal-combustion flue gas across full-scale units configured with small ESPs. The project is being funded by the U.S. DOE National Energy Technology Laboratory under this Cooperative Agreement. EPRI, Southern Company, and Georgia Power are project co-funders. URS Group is the prime contractor.

Various sorbent materials were injected upstream of low SCA ESP systems at Georgia Power’s Plant Yates Unit 1 and Unit 2. Both Unit 1 and Unit 2 fire a low sulfur bituminous coal. Unit 1 is equipped with a JBR wet FGD system downstream of the ESP for SO_2 control. Unit 2 is not equipped with downstream SO_2 controls; however, a dual flue gas conditioning system is used to enhance ESP performance.

Short-term parametric tests were conducted on Units 1 and 2 to evaluate the performance of activated carbon sorbents. In addition, the effects of the dual flue gas conditioning system on mercury removal performance were evaluated as part of the short-term parametric test on Unit 2. Based on the results of the parametric tests, a single sorbent will be selected for longer term full-scale tests on Unit 1 to observe long term performance of the sorbent, and its effects on ESP and JBR FGD system operations and combustion byproduct properties. The results of this study will provide data required for assessing the performance, long-term operational impacts, and estimating the costs of full-scale sorbent injection processes for flue gas mercury removal.

This is the third full reporting period for the subject Cooperative Agreement. During this period, parametric tests on Unit 1 were completed with the Super HOK carbon. The analysis of the parametric tests with Darco FGD™ carbon on Units 1 and 2 was completed, and the analysis of parametric tests with Ningxia Huahui (NH) activated carbon was completed. This technical progress report provides an update on these activities.

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List of Acronyms

acfm	Actual cubic feet per minute
ACI	Activated Carbon Injection
APCD	Air pollution control device
APH	Air preheater
ASTM	American Society for Testing and Materials
CEM	Continuous emissions monitor
CO_2	Carbon dioxide
CT-121	Chyodia Thoroughbred - 121
CVAA	Cold vapor atomic absorption
ΔP	"Delta P", Pressure drop or pressure difference
DOE	Department of Energy
EPA	Environmental Protection Agency
EPRI	Electric Power Research Institute
ESP	Electrostatic precipitator
FGD	Flue gas desulfurization
FGD™	Norit America's Darco FGD™ activated carbon
HCl	Hydrochloric acid
Hg	Mercury
HOK	RWE Rhinebraun's Super HOK activated carbon
IGS	Inertial gas separation
JBR	Jet bubbling reactor
LOI	Loss on ignition
MW	Megawatt
NETL	National Energy Technology Laboratory
NH Carbon	Ningxia Huahui Activated Carbon
NH_3	Ammonia
NIST	National Institute of Standards and Technology
NO	Nitrogen oxide
NO_2	Nitrogen dioxide
NO_X	Nitrogen oxides
OH	Ontario Hydro
PSD	Particle size distribution
QA/QC	Quality assurance/quality control
SCA	Specific collection area
SCEM	Semi Continuous Emission Monitor
SO_2	Sulfur dioxide
SO_3	Sulfur trioxide
U.S.	United States

1.0 Executive Summary

This document summarizes progress on Cooperative Agreement DE-FC26-03NT41987, "Sorbent Injection for Small ESP Mercury Control in Low Sulfur Eastern Bituminous Coal Flue Gas," during the time-period April 1, 2004 through June 30, 2004. The objective of this project is to demonstrate the ability of various activated carbon sorbents to remove mercury from coal-combustion flue gas across full-scale units configured with small ESPs. The project is being funded by the U.S. DOE National Energy Technology Laboratory under this Cooperative Agreement. EPRI, Southern Company, and Georgia Power are project co-funders. URS Group is the prime contractor.

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The primary activities during this third quarter of the test program were the completion of short term parametric testing for Unit 1 and continuation of analysis of the data gathered from the Units 1 and 2 parametric testing. Unit 1 tests included both Ningxia Huahui (NH) activated carbon and Super HOK injection tests at injection rates ranging from 2 to 13 lb/MMacf. Key results from this quarter are summarized below.

Unit 1 and Unit 2 ESP Mercury Removal

During baseline testing on Unit 1 (SCA = 173 ft^2/1000 acfm), the average vapor-phase ESP inlet mercury concentration was 4.02 μg/Nm^3 and the average ESP outlet concentration was 2.64 μg/Nm^3 (at 3% O_2). On average, a 34% native removal across the ESP was measured during the baseline period. For Unit 2 (SCA = 144 ft^2/1000 acfm) , during the baseline week of testing, the average ESP inlet mercury concentration was 6.04 μg/$Nm^3$and the outlet was 3.89 μg/Nm^3, indicating 36% native removal.

During the three weeks of carbon injection, native removals (i.e. no sorbent injection) of total vapor phase mercury were similar for both ESPs with values generally in the range of 25 to 50 percent. Injection of Darco FGD™ carbon increased removal to 45 to 60% across the ESP at injection rates of 2.3 to 4 lb/Mmacf (this removal percentage includes native removal of mercury across the ESP). Removal curves for all sorbents tested on the Unit 1 and Unit 2 ESPs were relatively flat at about 60 to 70 percent removal for injection rates greater than 6 lb/Mmacf (removal includes native removal of mercury).

Baseline total vapor-phase mercury emissions at the Unit 1 ESP outlet were between 2.1 lb/trillion Btu and 2.9 lb/trillion Btu. For all three tested sorbents (Darco FGD™, Super HOK,and NH Carbon), injection rates greater than 6 lb/MMacf were required to provide outlet emissions consistently lower than 2 lb/trillion Btu.

Tests on Unit 2 were conducted with the dual flue gas conditioning system off and on at various NH_3/SO_3 injection rates; however, flue gas conditioning was found to have no effect on total vapor-phase mercury removal across the ESP.

Because native removals were quite high, mercury removal was also evaluated as the percent reduction in mercury achieved at the ESP outlet as compared to the daily baseline ESP outlet concentration. This metric quantified performance improvements attributed to carbon injection. These data indicate similar percent reductions were achieved for all three sorbents on the Unit 1 ESP. Maximum reductions of about 40 percent were observed at injection rates in the range of 6 to 8 lb/MMacf with little additional reduction observed at the higher injection rates.

Impacts of Sorbent Injection on ESP Performance

Injection of activated carbon upstream of the Unit 1 ESP resulted in increased arc rates within all fields of the ESP with arc rates becoming more severe as the carbon injection rate was increased. Similar behavior was seen on Unit 2. Injection of activated carbon did not appear to increase the particulate emission rate from either the Unit 1 or Unit 2 ESPs.

2.0 Experimental

Experimental-related activities conducted during this quarter included the parametric tests of Super HOK activated carbon injection for Unit 1.

2.1 Plant Configuration

Figures 2-1 and 2-2 show the basic plant configuration, sorbent injection points, and flue gas sample locations for Units 1 and 2, respectively. Characteristics of each unit are summarized in Table 2-1.

Table 2-1. Plant Yates Unit 1 and 2 Configurations

	Yates Unit 1	Yates Unit 2
Boiler		
Type	CE Tangential Fired	
Nameplate (MW)	100	
Coal		
Type	Eastern Bituminous	
Sulfur (wt %, dry)	1.0	
Mercury (mg/kg, dry)	0.06-0.14	
Chloride (mg/kg, dry)	150-450	
ESP		
Type	Cold-Side	
ESP Manufacturer	Buell (1968 and 1971 vintage, refurbished in 1997)	
Specific Collection Area (ft^2/1000afcm)	173	144
Plate Spacing (in.)	11	
Plate Height (ft)	30	
Electrical Fields	3	2
Mechanical Fields	4	3
ESP Inlet Temp. (°F)	310	300
ESP Design Flow Rate (ACFM)	490,000	420,000
NO_x Controls	Low NOx Burners	None
SO_2 Controls	Chiyoda CT-121 wet scrubber (JBR)	None
Flue Gas Conditioning	None	Dual NH_3/SO_3

2.2 Experimental Methods

The sorbent injection equipment was described in the first technical report. The mercury measurements for baseline and injection testing were performed with mercury semi-continuous analyzers, which are described below in more detail. For each sorbent injection test, particulate loading was measured via Method 17 at one point in the duct. During baseline testing, Ontario Hydro, Method 26a measurements for halogens, and particulate loading via Method 5 were conducted. These methods are not explained further, as they are considered standard methods.

Solid and liquid samples, such as makeup water, fly ash, and coal, were collected and analyzed for mercury content. Fly ash and coal mercury were digested with ASTM 3684 and analyzed for mercury by CVAA. The coal was digested by ASTM 4208 and analyzed for chloride by Method 300.

EPRI SCEM Mercury Analyzer

Additional details regarding the SCEM mercury analyzer are provided in this section since it is not standard EPA method. Flue gas vapor-phase mercury analyses were made using EPRI semi-continuous analyzers depicted in Figure 2-3. At each sample location, a sample of the flue gas is extracted from the duct and then passes through an inertial gas separation (IGS) filter to remove particulate matter. This IGS filter consists of a heated stainless steel tube lined with sintered material. A secondary sample stream is pulled across the sintered metal filter and then is directed through the mercury analyzer at a rate of approximately 1-2 L/min, thus providing near real-time feedback during the various test conditions. The analyzer consists of a cold vapor atomic absorption spectrometer (CVAAS) coupled with a gold amalgamation system (Au-CVAAS). Since the Au-CVAAS measures mercury by using the distinct lines of the UV absorption characteristics of elemental mercury, the non-elemental fraction is converted to elemental mercury prior to analysis using a chilled reduction solution of acidified stannous chloride. Several impingers containing alkaline solutions are placed downstream of the reducing impingers to remove acidic components from the flue gas; elemental mercury is quantitatively transferred through these impingers.

Gas exiting the impingers flows through a gold amalgamation column where the mercury in the gas is adsorbed (<60° C). After adsorbing mercury onto the gold for a fixed period of time (typically 1-3 minutes), the mercury concentrated on the gold is thermally desorbed (>400° C) in nitrogen or air, and sent as a concentrated mercury stream to a CVAAS for analysis. Therefore, the total flue gas mercury concentration is measured semi-continuously with a 1 to 3-minute sample time followed by a 2-minute analytical period. The analyzer sampling time is set to ensure collection of nominally 3 ng of mercury per sampling cycle. The noise level of the analyzer is approximately 0.3 ng.

To measure elemental mercury only, an impinger containing either 1M potassium chloride (KCl) or 1M Tris Hydroxymethyl (aminomethane) and EDTA is placed upstream of the alkaline solution impingers to capture oxidized mercury. Oxidized forms of mercury are captured and maintained in the KCl or Tris impingers while elemental mercury passes through to the gold system. Comparison of "total" and "elemental" mercury measurements yields the extent of mercury oxidation in the flue gas.

2.3 Progress by Task

Progress on the various project tasks are described in the following sections. A summary of progress is provided in Table 2-2.

Table 2-2. Schedule for FY 2004 Milestones for this Test Program

Milestone	Description	Planned Completion	Actual Completion
1	Hazardous substance plan	Q1	Q1
2	Project kickoff meeting	Q1	Q1
3	Site Survey – Units 1 and 2	Q1	Q1
5	Test plan – Units 1 and 2	Q1	Q2
6	Complete sorbent injection system installation for parametric tests – Units 1 and 2	Q2	Q2
7	Complete baseline and parametric tests for sorbent 1 (Darco FGD™ carbon) on Units 1 and 2	Q2	Q2
8	Complete baseline and parametric tests for sorbent 2 (Super HOK carbon) on Unit 1	Q3	Q3
9	Transfer and install ACI silo and feeder system on Unit 1 for long-term tests	Q4	
10	Initiate long-term test on Unit 1	Q4	
11	Complete long-term test on Unit 1	Q4	
12	Complete data workup for Units 1 and 2	Q1-FY2005	
13	Initiate economic analysis	Q1-FY2005	

Task 1 – Project Planning

During the previous quarter, three different sorbents were selected for testing on Unit 1. A description of the each sorbent is provided in the Table 2-3.

Table 2-3. Sorbents Selected for Test Program

Carbon Name	Manufacturer	Description	Cost ($/lb)
Darco FGD™	Norit Americas	Lignite-derived activated carbon; baseline carbon (19 μm mean particle size)	0.50
Super HOK	RWE Rhinebraun	German lignite-derived activated carbon (23 μm mean particle size)	0.35 [a]
NH Carbon	Ningxia Huahui Activated Carbon Co. LTD (HHAC)	Chinese iodated bituminous-derived activated carbon (24 μm mean particle size)	0.88

a = F.O.B. Pennsylvania

Task 2 – Unit 1 Testing

Short-term parametric tests using the Super HOK activated carbon were conducted the week of April 5, 2004. Results from on-going analysis of these data, plus data from injection tests completed in the previous quarter, will be presented in this report.

Task 3 – Unit 2 Testing

The Unit 2 testing with Darco FGD™ carbon was completed during the previous reporting quarter. Results from on-going analysis of the Unit 2 test data will be presented in this report.

Task 4 – Data and Economic Analysis

Analytical and process data from the Unit 1 and Unit 2 parametric tests were reduced and analyzed. Initial results were presented in the previous quarterly report. In this current reporting period, more process and analytical data have been received and analyzed. No activity was conducted related to the economic analysis.

Task 5 – Waste Characterization

No samples for waste characterization were taken during the current reporting period.

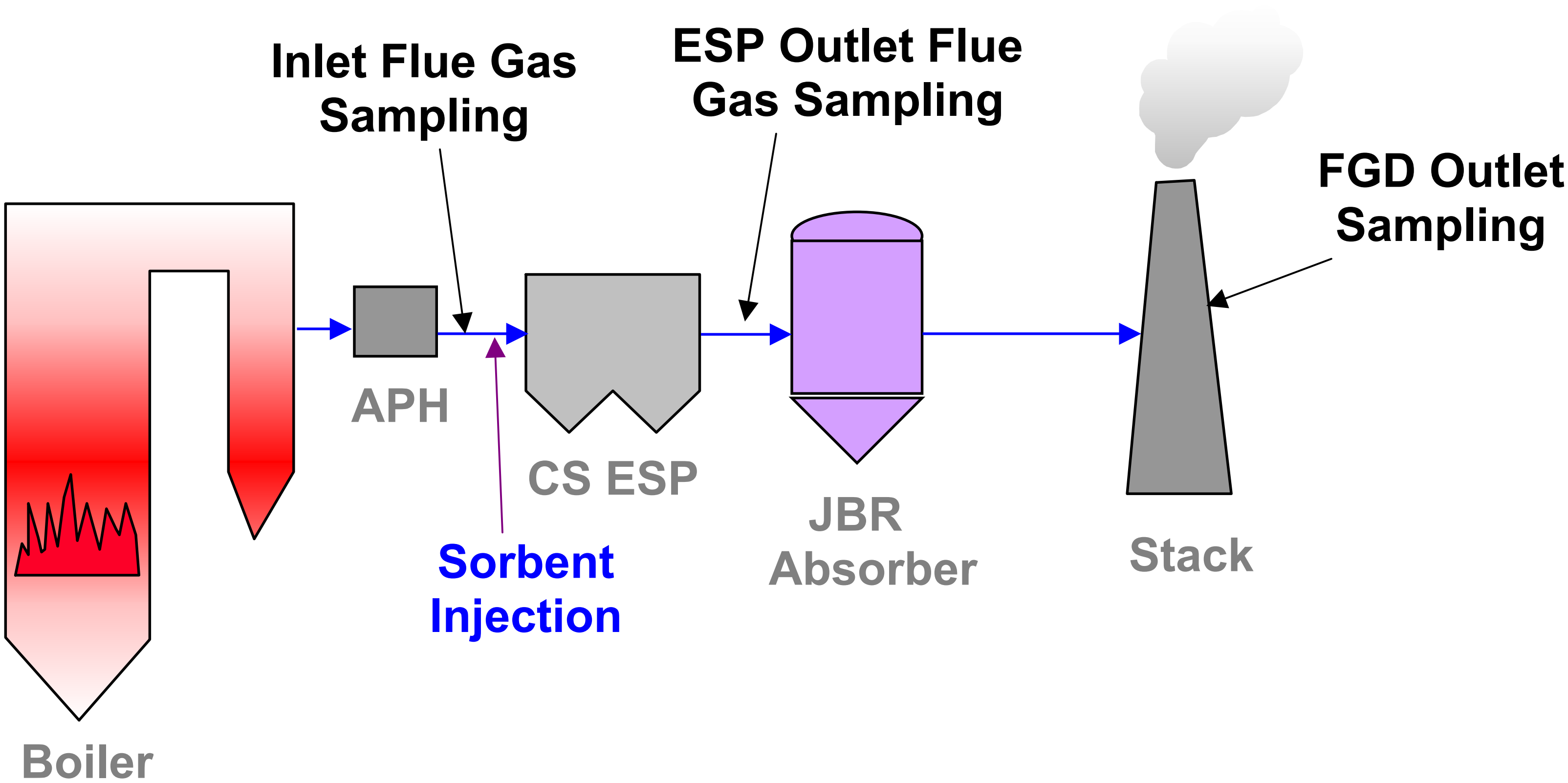

Figure 2-1. Unit 1 Configuration and Flue Gas Sample Locations

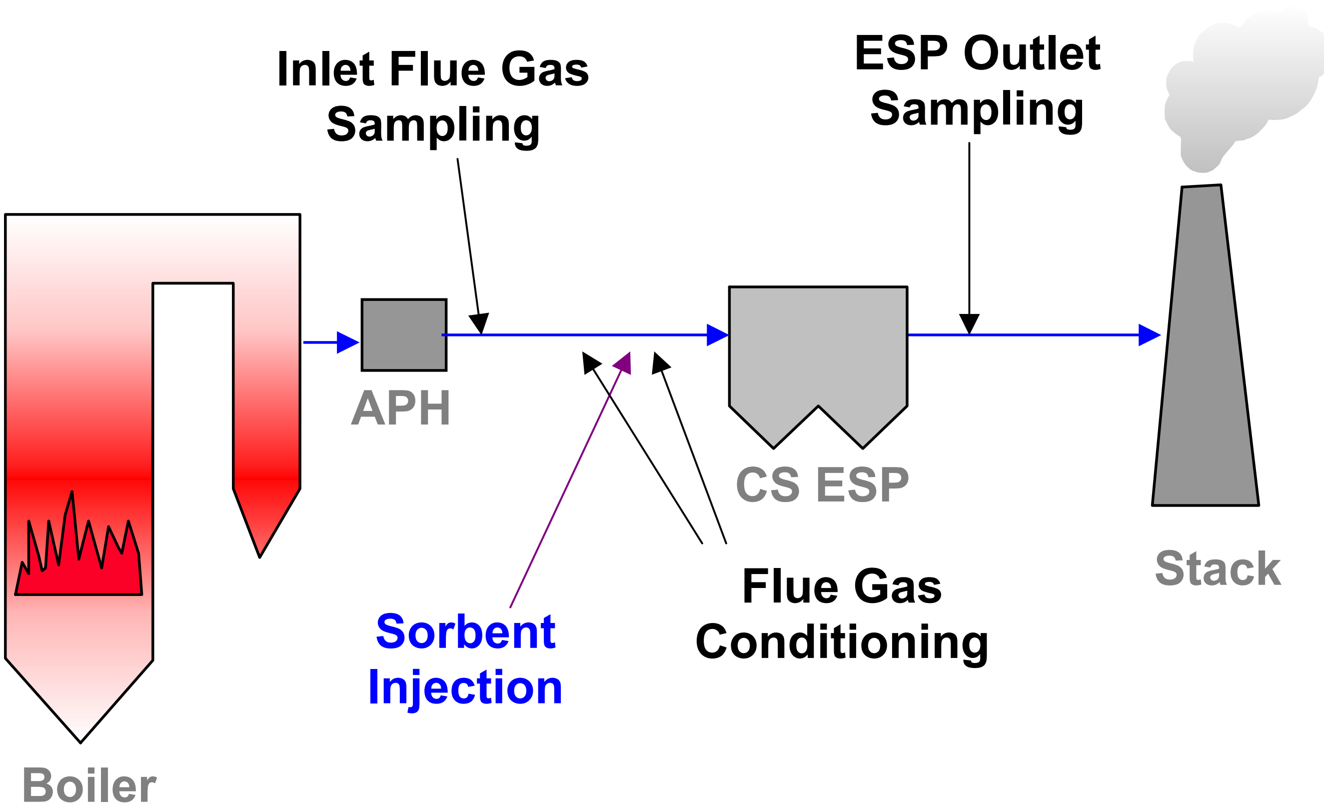

Figure 2-2. Unit 2 Configuration and Flue Gas Sample Locations

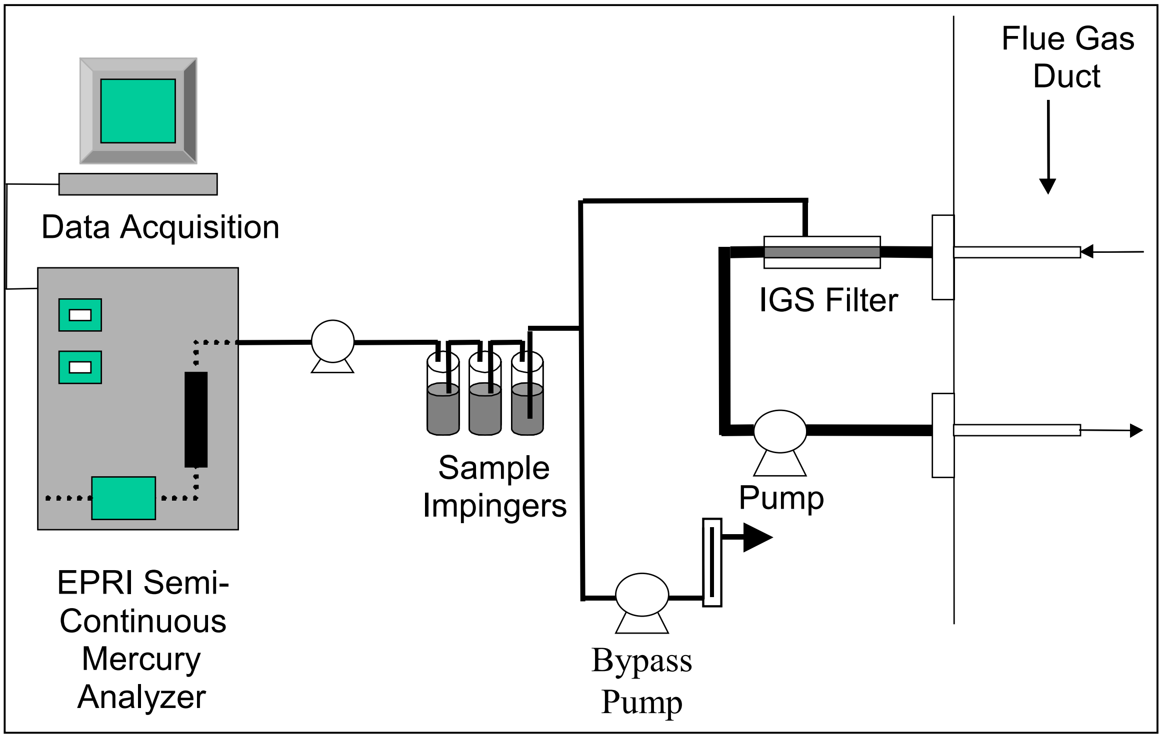

Figure 2-3. Semi-Continuous Mercury Analyzer

3.0 Results and Discussion

Results for the Unit 1 parametric tests using the Ningxia Huahui (NH) and Super HOK activated carbon are included in this quarterly report. Initial results from the Unit 1 and Unit 2 Darco FGD™ tests were presented in the previous quarterly report. Further analyses of the data are explored in this report.

3.1 Unit 1 Parametric Testing

Sorbent injection tests were conducted on Unit 1 for three different sorbents. The Darco FGD™ and NH carbon were tested during the previous quarter. The Super HOK was tested during this quarter.

3.1.1 Test Conditions and Modification to Test Plan

In the original test plan, two carbons were scheduled for testing on Unit 1: Darco FGD™ and Super HOK. The Darco FGD™ was tested as planned; however, the Super HOK carbon did not arrive to the test site as scheduled. Because the extent of the delay was not known until the planned commencement of the Super HOK tests, the testing staff was already on-site. Since another activated carbon, an iodated carbon manufactured in China (NH carbon), was available on-site, it was tested for two days. Testing staff then left the Yates site and returned one week later to perform the Super HOK testing. Testing of the Super HOK was accomplished in two days (rather than the planned five days). The time spent at each injection rate was reduced to 2-4 hours (rather than the planned eight hours). Previous injection testing on Units 1 and 2 indicated that two hours was sufficient time to reach a steady state flue gas mercury concentration.

Tables 3-1 and 3-2 show the sorbent injection rates that were tested for each of the carbon sorbents.

Table 3-1. Field Test Conditions for the Unit 1 Super HOK Parametric Tests

Date	Day 1 4/6/04		Day 2 4/7/04			
Injection Time Period (EST)	10:35-11:01	11:01-12:45	12:55-14:47	14:47-16:45	16:45-19:09	19:09-20:00
Actual Injection Rate (lb/MMacf)	17.0	12.9	3.3	6.0	8.8	10.2
Actual Injection Rate (lb/hr)	496	372	95	174	253	293

Table 3-2. Field Test Conditions for the Unit 1 NH Activated Carbon Parametric Tests

Date	Day 1 3/29/04		Day 2 3/30/04	
Injection Time Period (EST)	12:02-14:10	14:10-19:02	9:00-11:05	11:05-12:45
Actual Injection Rate (lb/MMacf)	4.2	6.3	8.3	12.5
Actual Injection Rate (lb/hr)	120	180	240	360

3.1.2 Unit 1 Process Operations

Unit 1 Boiler Operation

Unit 1 load was increased to its full-load set point of approximately 106 MW before each baseline and sorbent injection test period and held constant throughout each test. During the Super HOK testing on April 7th, boiler load dropped for one hour because of a miscommunication with the control room.

Unit 1 ESP Performance

Flue gas temperatures at the air heater outlet (ESP inlet) and ESP outlet, as measured by plant instrumentation, are shown in Figures 3-1 and 3-2. Figure 3-1 shows data for the days on which the Super HOK carbon was tested. Figure 3-2 shows data for the days on which the NH carbon was tested. Temperatures are shown for the two ducts exiting the air heater (labeled A and B side). The A-side duct, which was the location of the flue gas extraction probe for the mercury analyzer, was consistently 20 to 25°F hotter than the B-side duct. The two ducts combine in the ESP and exit as a single gas stream. A 30 to 40°F decrease in temperature was observed between the ESP inlet (A-side) and ESP outlet measurement locations, presumably due to air in-leakage across the ESP, mixing of the cooler B-side gas with the A-side gas, and gas cooling in the approximately 50-foot run of duct between the outlet of the ESP and the outlet temperature measurement point.

The flue gas mercury concentrations at the air heater outlet are also shown in Figures 3-1 and 3-2. These plots indicate that trends in the mercury concentration typically coincided with temperature changes in the air heater outlet duct. The most notable changes in mercury concentration were between periods of full load and partial load, when the air heater outlet temperature encountered its greatest change. At full load, mercury concentrations typically ranged from 5 to 7 $\mu g/Nm^3$ while at partial load, the mercury concentration was in the 3 to 4 $\mu g/Nm^3$ range.

The impact of sorbent injection on the ESP performance was quantified by taking Method 17 particulate samples at a single point in the duct during each injection rate and by monitoring the arc rate in each field. The flue gas particulate concentration was measured at the ESP outlet during baseline and injection testing. During baseline testing, a Method 5 filter was used in conjunction with Method 26 measurements. During injection testing, Method 17 was employed at a single point in the duct.

Figure 3-3 shows the Unit 1 ESP outlet particulate concentrations measured during baseline and injection testing. During baseline conditions (sorbent injection rate = 0 lb/MMacf), the ESP outlet particulate concentration ranged from 0.024 to 0.052 grains/dscf at 3% O_2, with an average of 0.036 gr/dscf. For the tested carbon injection rates of 2 to 17 lb/MMacf, the measured outlet particulate concentrations were mostly within or below the range of concentrations measured during baseline testing. These results indicate that carbon injection caused no significant increase in ESP outlet particulate concentration.

Very low ESP spark rates were observed throughout the testing period. Electrical problems in an ESP typically begin as sparks and if a spark is sustained, it becomes an arc. This usually happens when there is a high concentration of particulate matter between the HV electrode (wire) and the collecting electrode (plate). According to the Plant Yates engineers, the typical arc rate for the Unit 1 ESP is 0-1 arc/minute, and sustained arc rates greater than 10 arc/min are considered unacceptable as they may damage the ESP. It is not rare, however, for an ESP field to have an arc rate over 10, it is only damaging if this rate is sustained. An increase level of arcing or sparking is just an indication that a system upset is occurring. (i.e. when you increase load you typically see an increase in spark and arc rate because there is an increase in PM loadings.) Once the system reaches an equilibrium state those levels usually go down with adjustments by the ESP control system. The two-hour injection tests were not long enough, however, to see if the arcing subsides.

The arcing behavior of the Unit 1 ESP during sorbent injection caused some concern among plant engineers because it exceeded typical guidelines. However, the arc rate of the Unit 1 ESP during baseline testing also exceeded normal guidelines for a majority of the time. Data were analyzed for full load operation (> 95% full load) during the baseline (no injection) testing week of 2/24/04. Table 3-3 shows the percentage of time at full load that each field sustained arc rates greater than 1arc/min and 10 arc/min. These data indicate that the first (A) field of the Unit 1 ESP spent more than half of its time with arc rates greater than 10 arcs/min while the other fields had a relatively low percentage of time where they where arcing at greater than 10 arcs/min. Furthermore, all four fields routinely encountered arc rates greater than one arc/minute.

Table 3-3. Spark Rate and Arc Rate of Unit 1 ESP Fields During Full (>95%) Load, Baseline Conditions

	Sparks/Minute		% of time at Full Load when Spark Rate Greater than:		Arcs/Minute		% of time at Full Load when Arc Rate Greater than:	
Field	**Average**	**St. Dev.**	**1 SPM**	**10 SPM**	**Average**	**St. Dev.**	**1 APM**	**10 APM**
1A	0.2	0.5	2%	0%	12.5	6.5	95%	65%
1B	0.2	0.5	2%	0%	4.0	3.6	70%	6%
1C	0.0	0.1	0%	0%	2.3	2.5	53%	1%
1D	0.0	0.1	0%	0%	1.5	2.1	37%	0%

During the Darco FGD^{TM} injection testing, arc rates reached 10 arc/min, and in some cases exceeded this value. The arcing behavior of the Unit 1 ESP caused some concern because it appeared to be influenced by sorbent injection and exceeded typical guidelines. Similar sparking and arcing behavior was noted on Unit 2, where arc rates both during sorbent injection and baseline exceeded 10 arc/min.

Figure 3-4 plots the arc rates for each field over the course of the week-long Darco FGD™ injection tests. This figure shows that the arcing of the ESP was related to the sorbent injection rate. On each day of sorbent injection, the arc rate increased over time and with increasing sorbent injection rates. However, the behavior of each individual field was unpredictable. For example, on 3/2/04 the final D field experienced arc rates as great as 25 arc/min, while the upstream fields were less than 10 arc/min. On the other three test days, the D field had the lowest arc rate of all four fields. During Unit 2 testing, sorbent injection rate and flue gas conditioning appeared to influence the electrical behavior.

3.1.3 Mercury Speciation and Removal Data for Unit 1

Baseline Characterization Tests

Baseline characterization of the mercury concentrations in the flue gas at the ESP inlet, ESP outlet, and stack locations were conducted over a three-day period on 2/25/04 through 2/27/04. During this period, semi-continuous data were collected for total vapor-phase mercury and elemental mercury (oxidized mercury calculated by difference) using three SCEM analyzers. In addition, simultaneous Ontario Hydro mercury speciation measurements were conducted at the ESP inlet and ESP outlet during full-load conditions to compare to the SCEM analyzer results. The objectives of this series of tests were: 1) to measure the native mercury concentrations at the various flue gas sample locations; 2) to measure the variability in flue gas mercury concentrations over time; and 3) to compare the performance of the SCEM analyzers with results from the Ontario Hydro standard reference method.

Table 3-4 provides a comparison of the baseline mercury measurements for the SCEM and Ontario Hydro methods. The average total and elemental mercury concentrations measured by the SCEM during the course of each two-hour Ontario Hydro run are reported. The SCEM measured ESP inlet concentrations between 3.92 and 4.12 $\mu g/Nm^3$ at 3% O_2, with an average of 4.02 $\mu g/Nm^3$. The three Ontario Hydro runs measured 8.96, 2.81, and 2.99 $\mu g/Nm^3$ at the ESP inlet, for an average of 4.92$\mu g/Nm^3$. At the ESP outlet, the SCEM measured 3.49, 2.26, and 2.18 $\mu g/Nm^3$, while the Ontario Hydro runs measured 7.01, 3.54, and 3.104 $\mu g/Nm^3$.

Particulate mercury concentrations are not available at the ESP inlet since the ESP inlet sampling location was nestled between two sharp turns in the ductwork, making isokinetic sampling infeasible. The ESP outlet particulate mercury concentrations, as determined by the Ontario Hydro method, were 0.0241 $\mu g/Nm^3$.

The inlet SCEM and Ontario Hydro data are within 18% of each other. However, the Ontario Hydro data indicate that the inlet stream is 88% oxidized, while the SCEM indicate 51% oxidation at the inlet. In Ontario Hydro a particulate filter is placed upstream of the impingers, allowing for intimate contact between the gas and the collected particulate matter. The SCEM method uses a self-cleaning filter, which minimizes the accumulation of particulate matter and minimizes the possibility of bias. These data indicate that the passage of flue gas through the Ontario Hydro particulate filter may have resulted in oxidation of sampled mercury. This hypothesis is further validated with the outlet data, in which the oxidation percentages of the Ontario Hydro and SCEM agree. At the ESP outlet, the flue gas had a very low particulate concentration, so the bias caused by collection of particulate on the filter was reduced.

It should be noted that while the average of the SCEM and Ontario Hydro inlet data are within 18% of each other, each individual run shows larger disparity. The first run is of particular concern. Both the inlet and outlet first run Ontario Hydro values are at least twice as high as their counterpart SCEM measurements. Furthermore, the first run Ontario Hydro values are 2-3 times as high as the two subsequent Ontario Hydro runs (while the SCEM showed more constant mercury concentrations over the same time period). The plant operational data does not indicate any reason to expect a large change in mercury concentration, as seen in the Ontario Hydro data.

A mass balance across the boiler/ESP system indicates 99% closure when performed with the SCEM ESP outlet data.

The discrepancies between the SCEM and Ontario Hydro results are under investigation. Furthermore, the differences between the first Ontario Hydro run and the subsequent runs are being explored. A review of the QC spike recovery data for the SCEM method does not indicate any problem with these data.

Table 3-4. Unit 1 - Comparison of Average SCEM and Ontario Hydro Mercury Measurements During Baseline Characterization on 2/26/04

	Run No.	Sampling Period (EST)	Vapor Phase			
			Elemental	Oxidized	Percent Oxidized	Total
ESP Inlet, μg/Nm^3						
SCEM	1	10:33-12:33	2.06	1.96	49	4.02
OH	1		1.25	7.71	86	8.96
SCEM	2	14:32-16:32	1.92	2.20	53	4.12
OH	2		0.30	2.51	89	2.81
SCEM	3	17:02-19:02	1.89	2.03	52	3.92
OH	3		0.41	2.59	86	2.99
SCEM	Avg	-	1.95	2.07	51	4.02
OH	Avg	-	0.65	4.27	88	4.92
ESP Outlet, μg/Nm^3						
SCEM	1	10:33-12:33	2.16	1.33	38	3.49
OH	1		5.25	1.76	25	7.01
SCEM	2	14:30-16:30	1.48	0.78	35	2.26
OH	2		1.73	1.82	51	3.54
SCEM	3	17:02-19:02	1.38	0.80	37	2.18
OH	3		1.65	1.44	47	3.10
SCEM	Avg	-	1.67	0.97	37	2.64
OH	Avg	-	3.05	1.67	41	4.55
Removal, %						
SCEM	Avg	-	14	53	NA	34
OH	Avg	-	-343	61	NA	8

Note: All data normalized to 3% oxygen. Oxidized mercury for SCEM calculated as difference between measured total and elemental mercury. Total mercury for OH calculated as sum of measured elemental and oxidized mercury.

Sorbent Injection Tests - Super HOK Carbon

Table 3-5 provides a summary of the average total vapor-phase mercury and mercury speciation data obtained for the sorbent injection tests using the SCEM mercury analyzer. A set of baseline mercury measurements with no injection was obtained at the beginning and at the end of each sorbent injection test day to provide a benchmark for the sorbent injection tests. Elemental mercury measurements were not obtained for every test condition because of the limited time frame in which to conduct the Super HOK testing. The time allocated for Super HOK testing was compressed from the original schedule because of problems in securing the delivery of the carbon to Plant Yates.

Figures 3-5 and 3-6 show the total mercury concentrations measured at the air heater outlet, ESP outlet, and the stack, along with the Super HOK carbon injection rate. Figure 3-5 is for the first day of testing, and Figure 3-6 is for the second day.

Removal performance of the ESP, JBR FGD and combined ESP/JBR FGD controls for the various tests, calculated based on the average SCEM results from Table 3-5, are provided in Table 3-6. Total vapor-phase mercury removal (i.e., ESP inlet compared to ESP outlet) is plotted as a function of sorbent injection rate in Figure 3-7 for the various test days. This calculation does not account for removal of particulate mercury across the ESP. Like the baseline characterization tests on 2/25/04 through 2/27/04, relatively high native removals of total vapor-phase mercury were observed without sorbent injection at the beginning and end of each sorbent injection test day. Native removal of total vapor-phase mercury across the ESP ranged from 47 to 59 percent, which may be due to the high carbon content of the ash generated by Unit 1 (approximately 11 to 14 percent LOI during the Super HOK carbon injection test period). Removal of mercury across the ESP appeared to plateau in the 66-75% range at injection rates of 9 lb/MMacf and greater (this removal percentage includes the native removal of mercury across the ESP).

Table 3-5. Average SCEM Mercury Measurements for Unit 1 During Baseline and Injection of Super HOK Carbon

		ESP Inlet			ESP Outlet			Stack		
Date	Rate (lb/MMacf)	Total Hg	Hg^0	% Oxidized	Total Hg	Hg^0	% Oxidized	Total Hg	Hg^0	% Oxidized
4/6/2004	0.0		2.28		3.15			2.52	2.61	-3%
	12.9	6.36	3.84	40%	2.19	0.84	62%	1.91	1.76	8%
	0.0				3.32			2.59		
4/7/2004	0.0				3.26					
	3.3	6.11			2.92			2.31		
	6.0				2.08			1.81		
	8.8	5.05			1.55	0.99	36%	1.41	1.54	-9%
	10.2	5.37			1.34			1.39		
	0.0	5.23			2.15			2.02		

Note: All concentrations are in units of μg/Nm^3 and are normalized to 3% oxygen.

Table 3-6. Summary of Measured Percent Removal of Vapor Phase Mercury Across ESP, JBR, and Combined ESP/JBR During Injection of Super HOK Carbon

		% Removal of Total Vapor Phase Hg		
Date	Rate (lb/MMacf)	Across ESP	Across JBR	Across ESP/JBR
4/6/2004	0.0	51%	20%	60%
	12.9	66%	13%	70%
	0.0	48%	22%	59%
4/7/2004	0.0	47%		
	3.3	52%	21%	62%
	6.0	59%	13%	64%
	8.8	69%	9%	72%
	10.2	75%	-4%	74%
	0.0	59%	6%	61%

A plot of total vapor-phase mercury removal across the ESP/JBR FGD system during sorbent injection tests is provided in Figure 3-8. Native removal values were approximately 60%. A slight increase in total mercury removal across the ESP/JBR FGD system was observed during the Super HOK activated carbon injection tests when compared to baseline. Total mercury removal values plateaued at 70-74 percent during sorbent injection at injection rates greater than 9 lb/Mmacf (this removal percentage includes the native removal of mercury across the ESP).

Because the native mercury removal was quite high, the amount of mercury reduction attributed to Super HOK carbon injection was estimated by calculating the percent reduction in average total vapor-phase mercury levels at the ESP outlet and Stack locations compared to average baseline levels (i.e., native levels). The percent reduction in total mercury concentration for a given injection rate was calculated as follows:

$$\text{Percent Reduction} = [1 - (I / BL)] \times 100$$

Where, I = average SCEM total mercury concentration at the ESP outlet or Stack for the injection rate test period, and

BL = average SCEM total mercury concentration at the ESP outlet or Stack for the baseline test period calculated based on the concentrations measured at the beginning and end of each test day.

Both Figures 3-9 and 3-10 show that additional mercury removal from sorbent injection plateaus around 9 lb/MMacf. For the Unit 1 ESP, Figure 3-9 indicates a 10 to 38 percent reduction in total vapor-phase mercury concentrations at the ESP outlet compared to baseline concentrations over the range of sorbent injection rates tested. At the Stack, a 10 to 30 percent reduction in total vapor-phase mercury concentrations was observed compared to baseline concentrations.

Sorbent Injection Tests-NH Carbon

Table 3-7 provides a summary of the average total vapor-phase mercury and mercury speciation data obtained for the NH carbon injection tests using the SCEM mercury analyzer. A set of baseline mercury measurements with no injection was obtained at the beginning and at the end of each sorbent injection test day to provide a benchmark for the sorbent injection tests. Figures 3-11 and 3-12 show the total mercury concentrations measured at the air heater outlet, ESP outlet, and the stack, along with the NH carbon injection rate. Figure 3-11 is for the first day of testing, and Figure 3-12 is for the second day.

At the ESP inlet location, the percentage of the total mercury present as oxidized mercury remained essentially unchanged between daily baseline and sorbent injection tests periods, with values generally in the range of 55 to 60 percent. These values were consistent with SCEM data obtained during the baseline characterization period of 2/25/04 through 2/27/04. During all test conditions, the flue gas exiting the stack was almost all elemental mercury.

Removal performance of the ESP, JBR FGD and combined ESP/JBR FGD controls for the various tests, calculated based on the average SCEM results from Table 3-7, are provided in Table 3-8. Total vapor-phase mercury removal across the ESP (i.e., ESP inlet compared to ESP outlet) is plotted as a function of sorbent injection rate in Figure 3-13 for the various test days. This calculation does not account for removal of particulate mercury across the ESP. Relatively high native removals of total vapor-phase mercury were observed without sorbent injection at the beginning and end of each sorbent injection test day. Native removal of total vapor-phase mercury across the ESP ranged from 16 to 38 percent, with an average of 27%, which probably results from the high carbon content of the ash generated by Unit 1 (approximately 8 to 9.5 percent LOI during the NH carbon injection test period). For the ESP system, the total mercury removal across the ESP was the highest at 61% at an injection rate of 6 lb/Mmacf (this removal percentage includes the native removal of mercury across the ESP). Tests at higher injection rates of 8.3 and 12.5 lb/MMacf resulted in 50% removal across the ESP (this removal percentage includes the native removal of mercury across the ESP). It should be noted that the native removal across the ESP was higher on the day that the 6 lb/MMacf rate was tested.

Table 3-7. Average SCEM Mercury Measurements for Unit 1 During Baseline and Injection of NH Carbon

Date	Rate (lb/MMacf)	ESP Inlet Total Hg	ESP Inlet Hg^0	ESP Inlet % Oxidized	ESP Outlet Total Hg	ESP Outlet Hg^0	ESP Outlet % Oxidized	Stack Total Hg	Stack Hg^0	Stack % Oxidized
3/29/2004	0.0		2.66	55%	4.11	1.94	53%	1.88	1.98	-6%
	4.2	5.89	2.36	60%	3.27			1.18		
	6.3	7.00			2.75	1.94	29%	1.12	1.16	-4%
	0.0	7.11			4.39			2.07		
3/30/2004	0.0				4.12	2.14	48%	1.86	1.64	11%
	8.3	5.51			2.74			0.88	0.86	2%
	12.5	4.88			2.40			0.66		
	0.0	4.70			3.97			1.43	1.40	2%

Note: All concentrations are in units of $\mu g/Nm^3$ and are normalized to 3% oxygen.

Table 3-8. Summary of Measured Percent Removal of Vapor Phase Mercury Across ESP, JBR, and Combined ESP/HBR During Injection of NH Carbon

Date	Rate (lb/MMacf)	% Removal of Vapor Phase Hg Across ESP	Across JBR	Across ESP/JBR
3/29/2004	0.0	30%	54%	68%
	4.2	44%	37%	80%
	6.3	61%	59%	84%
	0.0	38%	53%	71%
3/30/2004	0.0	25%	55%	66%
	8.3	50%	68%	84%
	12.5	51%	73%	87%
	0.0	16%	64%	70%

A similar plot of total vapor-phase mercury removal across the ESP/JBR FGD system during sorbent injection tests is provided in Figure 3-14. Native removal values were in the range of 66 to 71 percent. A slight increase in total mercury removal across the ESP/JBR FGD system was observed during the NH activated carbon injection tests when compared to baseline. Total mercury removal values ranged from 80 to 87 percent during sorbent injection tests with the maximum value observed at an injection rate of 12.5 lb/Mmacf (this removal percentage includes the native removal of mercury across the entire system). These removal levels are higher than the overall removals measured during Darco FGD™ injection (66-82% including native mercury removal). However, overall native removals were higher during the NH carbon test period (66-71%) as compared to the Darco FGD™ test period (45-65%). The primary contribution to the higher overall native removals during the NH carbon test period was significantly higher mercury removal efficiency in the JBR.

Because the native mercury removal was quite high, the amount of mercury reduction attributed to NH carbon injection was estimated by calculating the percent reduction in average total vapor-phase mercury levels at the ESP outlet and Stack locations compared to average baseline levels (i.e., native levels). Both Figures 3-15 and 3-16 show that additional mercury removal from sorbent injection plateaus around 6-8 lb/MMacf. For the Unit 1 ESP, Figure 3-15 indicates a 20 to 40 percent reduction in total vapor-phase mercury concentrations at the ESP outlet compared to baseline concentrations over the range of sorbent injection rates tested. At the Stack, a 37 to 54 percent reduction in total vapor-phase mercury concentrations was observed compared to baseline concentrations.

Figure 3-17 shows the total vapor-phase mercury emissions, expressed as lb/trillion Btu input, at the ESP outlet as a function of carbon injection rate. The corresponding daily baseline vapor-phase mercury concentrations are also provided for comparison. Without injection, the ESP outlet emissions ranged from 2.8 to 3.0 lb/trillion Btu. NH carbon injection rates of greater than 6 lb/MMacf were required to reduce ESP outlet emissions below 2 lb/trillion Btu. Beyond injection rates of 6 lb/MMacf, vapor-phase mercury emissions remained relatively constant.

3.1.4 Comparison of Performance of Darco FGD™, Super HOK, and NH Carbon

Figures 3-18 through 3-21 are composites of plots presented earlier in this report and in the previous technical report. Figures 3-18 and 3-19 show the percent mercury removal across the ESP and ESP/JBR combination, respectively. Figures 3-20 and 3-21 show the percent reduction of mercury at the ESP outlet and stack, respectively.

Figures 3-18 and 3-20 indicate that the three sorbents produce similar mercury removal/reduction results on the Unit 1 ESP. For all three carbons, removal across the ESP plateaued between 50 and 70% for injection rates greater than 9 lb/Mmacf (These removal percentages include native removal of mercury across the ESP). For the three carbons, the maximum achieved percent reduction of mercury at the ESP outlet as a result of carbon injection was about 40%. The curves for the Darco FGD™ and the NH carbon are nearly identical, and the Super HOK curve is just slightly lower. At the stack, the NH carbon resulted in the highest combined removal across the ESP/JBR. However, the native removal across the combined system was higher for the NH Carbon injection testing than during the other injection tests. The reduction of mercury at the stack was higher for the NH carbon. The Darco FGD™ and the Super HOK curves were nearly identical.

All three sorbents were capable of bringing the Unit 1 ESP emissions below 2 lb/trillion. A sorbent injection rate of at least 6 lb/MMacf is needed to achieve the target emission rate.

3.1.5 Coal, Fly Ash, JBR FGD Byproducts, and Other Process Streams

Coal

Table 3-8 shows the analytical results for as-fired coal samples. Composite samples of the Unit 1 coal were collected twice per day downstream of the coal pulverizers and were analyzed in triplicate for mercury; an average of the triplicate analyses is reported in the table. Ultimate/proximate and chlorine analyses were performed on selected samples, and these results are also shown. For the test days on which the as-fired coal was not analyzed, the proximate analyses are for the as-bunkered coal samples are given. These as-bunkered data were provided by Plant Yates.

As the coal Hg content increased, the measured vapor phase mercury at the air heater outlet increased, as shown by Figure 3-22. This plot does not account for particulate phase mercury, which could not be measured due to severe cyclonic flow at the sampling location.

Bottom Ash and Fly Ash

Table 3-10 shows the results for mercury and LOI analyses of the bottom ash and ESP fly ash samples. Composite fly ash samples were obtained by collecting and combining ash from each field of the ESP during the baseline characterization and sorbent injection test periods. A single grab sample of bottom ash was obtained. Results from baseline and the three sorbent injection test periods are shown.

There was no apparent increase in the carbon content of the ESP fly ash, as measured by percent LOI, for the activated carbon injection tests compared to the baseline tests. As shown in Figure 3-23, the mercury content of both the bottom ash and the ESP fly ash samples were directly related to the percent LOI of the ash.

Table 3-9. Unit 1 - Coal Analyses for Baseline and Carbon Injection Tests

Date	**2/24**	**2/25**	**2/25**	**2/26**	**2/26**	**2/27**	**2/27**	**3/1**	**3/1**	**3/2**	**3/2**	**3/3**	**3/3**	**3/4**	**3/4**
Sample Time	**13:30**	**9:20**	**12:30**	**9:20**	**13:00**	**9:00**	**12:10**	**10:00**	**13:05**	**9:30**	**13:05**	**9:30**	**13:10**	**9:10**	**13:00**
Test Condition [a]	**BL**	**BL**	**BL**	**BL**	**BL**	**BL**	**BL**	**FGD**	**FGD**	**FGD**	**FGD**	**FGD**	**FGD**	**FGD**	**FGD**
Proximate, wt % as received [b]															
Moisture	6.67	-	6.65	-	7.22	-	6.5	-	6.04	-	5.38	-	5.16	-	5.89
Ash	12.64	-	13.27	-	13.04	-	10.16	-	11.64	-	10.63	-	11.12	-	10.99
Volatile Matter	28.32	-	27.86	-	27.4	-	28.43	-	27.91	-	28.94	-	28.80	-	28.05
Fixed Carbon	52.38	-	52.23	-	52.33	-	54.90	-	54.41	-	55.05	-	54.92	-	55.07
Sulfur	0.76	-	0.73	-	0.91	-	1.29	-	0.93	-	0.95	-	0.93	-	1.16
Ultimate, wt % as received															
Moisture	-	-	3.62	-	-	-	-	-	-	-	-	-	4.40	-	-
Carbon	-	-	72.64	-	-	-	-	-	-	-	-	-	72.49	-	-
Hydrogen	-	-	4.66	-	-	-	-	-	-	-	-	-	4.69	-	-
Nitrogen	-	-	1.40	-	-	-	-	-	-	-	-	-	1.36	-	-
Sulfur	-	-	0.87	-	-	-	-	-	-	-	-	-	0.99	-	-
Oxygen	-	-	5.82	-	-	-	-	-	-	-	-	-	5.01	-	-
Ash	-	-	10.99	-	-	-	-	-	-	-	-	--	11.06	-	-
Heating Value (Btu/lb, as received)	12253[b]	13102	12196	-	12218[b]	-	12803[b]	-	12651[b]	-	12849[b]	-	12993	-	12730[b]
Mercury (µg/g, dry)	0.062	0.062	0.063	0.059	0.062	0.075	0.086	0.084	0.064	0.071	0.076	0.065	0.081	0.073	0.11
Mercury (lb/trillion Btu)	5.1	4.7	5.2		5.1	-	6.7	-	5.1	-	5.9	-	6.2	5.7	8.6
Chloride (mg/Kg, dry)		274	237		362	-	-	-	285	-	-	-	128	-	-

[a] BL = baseline characterization, FGD = Darco FGD™ carbon sorbent injection; NH = NH carbon sorbent injection; HOK = HOK sorbent injection
[b] Represents Plant Yates analysis of as-bunkered fuel samples. Mercury analysis was done on separate Unit 1 as-fired coal samples.

Table 3-9. Unit 1 - Coal Analyses for Baseline and Carbon Injection Tests (continued)

Date	**3/29**	**3/29**	**3/30**	**3/30**	**4/6**	**4/6**	**4/7**	**4/7**	**4/8**
Sample Time	**9:30**	**13:10**	**9:20**	**13:20**	**10:00**	**13:20**	**9:30**	**13:30**	**9:30**
Test Condition [a]	**NH**	**NH**	**NH**	**NH**	**HOK**	**HOK**	**HOK**	**HOK**	**HOK**
Proximate, wt % as received [b]									
Moisture	-	5.5	-	7.19	-	5.67	-	5.86	-
Ash	-	12.27	-	11.86	-	11.22	-	11.16	-
Volatile Matter	-	28.26	-	27.82	-	26.95	-	26.52	-
Fixed Carbon	-	53.97	-	53.14	-	56.16	-	56.45	-
Sulfur	-	0.86	-	0.86	-	0.89	-	0.89	-
Ultimate, wt % as received									
Moisture	-	-	-	5.28	-	-	-	6.21	-
Carbon	-	-	-	71.75	-	-	-	69.31	-
Hydrogen	-	-	-	4.61	-	-	-	4.36	-
Nitrogen	-	-	-	1.49	-	-	-	1.31	-
Sulfur [b]	-	-	-	1.03	-	-	-	0.93	-
Oxygen	-	-	-	4.86	-	-	-	5.68	-
Ash	-	-	-	10.98	-	-	-	12.20	-
Heating Value (Btu/lb, as received)	-	12606[b]	-	12933	-	12789[b]	-	12467	-
Mercury (µg/g, dry)	-	.071	-	.056	-	.086	-	.073	0.119
Mercury (lb/trillion Btu)	-	5.6	-	4.3	-	6.7	-	5.9	-
Chloride (mg/Kg, dry)	-	201	-	-	-	452	-	-	-

Table 3-10. Unit 1 – Bottom Ash and ESP Fly Ash Analyses for Baseline Characterization and Sorbent Injection (SI) Tests

Date	Time	Sample Type	Test Condition	Injection Rate (lb/MMacf)	Mercury (µg/g)	LOI (%)
2/24	13:15	ESP ash	Baseline	0	0.31	11.8
2/25	9:46	ESP ash	Baseline	0	0.26	9.9
2/25	13:10	ESP ash	Baseline	0	0.28	10.2
2/26	10:00	ESP ash	Baseline	0	0.33	12.8
2/26	13:00	Bottom Ash	Baseline	0	0.003	0.44
3/1	11:00	ESP ash	Darco FGD™ SI	6.3	0.32	12.8
3/2	13:30	ESP ash	Darco FGD™ SI	12.7	0.25	7.2
3/3	13:35	ESP ash	Darco FGD™ SI	4.2	0.27	8.5
3/4	13:30	ESP ash	Darco FGD™ SI	7.3	0.25	6.8
3/29	13:20	ESP ash	NH Carbon SI	4.2	0.182	7.97
3/30	13:20	ESP ash	NH Carbon SI	12.5	0.337	9.46
4/6	13:30	ESP ash	Super HOK SI	12.9	0.510	13.71
4/7	13:20	ESP ash	Super HOK SI	3.3	0.353	11.41

Mercury Mass Balance

A preliminary overall mass balance for mercury was estimated based on the measured concentrations of mercury in the coal, bottom ash, ESP fly ash, JBR FGD slurry blowdown liquor and solids (gypsum), limestone, JBR FGD makeup water, and stack outlet gas on 2/26/04. As an additional data check, mass balances for mercury were computed around the boiler and the ESP as well as around the JBR. A mass balance around the ESP was not possible because the poor sampling location at the ESP inlet precluded isokinetic sampling. Therefore, particulate loading measurements were not possible.

Mass balance results for the baseline period are shown in Table 3-8. Process stream flow rates used in the mass balance calculations were estimated based on plant process data or calculated as indicated in Table 3-8. All mercury vapor concentrations listed in Table 3-8 are at actual oxygen levels. Mercury balance closure for the entire plant was 130 percent. The mass balance around the boiler/ESP system was (99%) indicating good agreement between coal mercury levels and outlet levels measured in the ESP fly ash and ESP outlet flue gas (SCEM). However, the balance around the JBR was 180%, which increased the uncertainty in the overall balance. The estimated mercury rates exiting in the slurry blowdown appear high. The pond water recycle flow rate was estimated as the difference between the required saturation water rate and the measured makeup water flow rate. This estimation may introduce additional error into the mass balance around the JBR. This preliminary mass balance indicates that approximately 60 percent of the mercury input with the coal was captured in the ESP fly ash.

Table 3-11. Unit 1 – Mercury Mass Balance Results for Baseline Characterization on 2/26/04

Stream	Flow Rate	Mercury Concentration[c]	Mercury Rate (g/hr)
Coal [a]	100,520 wet lb/hr	0.0604 dry µg/g	2.553
Bottom Ash [a]	2,622 lb/hr	0.003 µg/g	0.004
ESP Outlet Vapor [a] (SCEM)	8,472 dry Nm^3/min	1.86 µg/ Nm^3	0.946
ESP Outlet Particulate [a] (OH)	8,472 dry Nm^3/min	0.008 µg/Nm^3	0.004
ESP Captured Fly Ash [a]	10,420 lb/hr	0.331 µg/g	1.564
Limestone [ae]	3,133 lb/hr	0.02 µg/g	0.028
Pond Water Recycle [a]	90 gpm	1.17 µg/L	0.024
Slurry Blowdown – Liquid [b]	136 gpm	15.07 µg/L	0.449
Slurry Blowdown – Solids [b]	5,964 lb/hr	0.166 µg/g	0.449
Stack Vapor [b] (SCEM)	9,170 dry Nm^3/min	1.63 µg/Nm^3	0.897
Mass Balance Around Boiler and ESP			
		Boiler/ESP In	2.553
		Boiler/ESP Out	2.517
		Closure [d]	99 %
Mass Balance Around JBR FGD System			
		JBR FGD In	1.002
		JBR FGD Out	1.795
		Closure [d]	179%
Overall Mass Balance			
		Total In	2.605
		Total Out	3.3362
		Closure [d]	**129%**

[a] Estimated stream flow rate
[b] Measured stream flow rate
[c] Mercury vapor concentrations at the actual flue gas oxygen content.
[d] Closure (%) = (Out/In) x 100

3.2 Unit 2 Parametric Testing

Baseline and parametric testing of Darco FGD™ on Unit 2 was conducted during the weeks of March 15th and March 22nd. Tests were conducted with the dual flue gas conditioning system both on and off to observe the effects on mercury speciation, removal, and ESP performance during sorbent injection.

3.2.1 Test Conditions and Modifications to Test Plan

Field test conditions for the Unit 2 baseline and Darco FGD™ activated carbon parametric tests are summarized below in Table 3-12. All sampling activities were completed as planned. Comprehensive baseline characterization of the Unit 2 system was conducted on 3/17/04 through 3/19/04; sorbent injection tests were conducted on 3/22/04 through 3/26/04.

Sorbent injection rates for the tests were selected based on the results of the Unit 1 Darco FGD™ sorbent injection tests. Tests were conducted using Darco FGD™ carbon injection rates ranging from 2.3 to 12.7 lb/MMacf (60 to 365 lb/hr), with the NH_3/SO_3 flue gas conditioning system both on and off.

3.2.2 Unit 2 Process Operations

Unit 2 Boiler Operation

Unit 2 load was increased to its full-load set point of approximately 105 MW before each baseline and sorbent injection test period and held constant throughout each test

Unit 2 ESP Performance

Figure 3-24 shows the air heater outlet temperature along with the air heater outlet mercury concentrations measured over the course of the sorbent injection testing week. The air heater outlet temperature logged in the plot is the average of the A side and B side ducts. Each day, once the unit achieved full load, the air heater outlet temperature continued to rise by up to 10°F. Toward the end of each test day, the temperature achieved a steady value of approximately 260-264°F. The air heater outlet vapor phase mercury concentration appeared to have a dependency upon the air heater outlet temperature. The mercury concentration was steady only when the air heater outlet temperature was steady.

Table 3-12. Field Test Conditions for the Unit 2 Darco FGD™ Carbon Parametric Tests

Date	Baseline, Full Load			Darco FGD™ Carbon Injection, Full Load												
	Day 1	Day 2	Day 3	Day 4		Day 5			Day 6				Day 7			
	3/17/04	3/18/04	3/19/04	3/22/04		3/24/04			3/25/04				3/26/04			
Sorbent Injection Time Period (EST)	NA	NA	NA	11:45 – 15:25	15:25 – 16:30	13:25 – 16:11	16:11 – 17:14	17:14 – 18:11	9:57 – 13:11	13:11 – 16:00	16:00 – 17:30	17:30 – 18:14	9:57 – 12:46	12:46 – 14:30	14:30 – 15:40	15:40 – 16:15
Sorbent Injection Rate (lb/MMacf)	0	0	0	2.1	4.2	6.3	8.3	12.7	2.1	4.2	4.2	4.2	4.2	4.2	4.2	4.2
Sorbent Injection Rate (lb/hr)	0	0	0	60	120	180	240	365	60	120	120	120	120	120	120	120
Dual Flue Gas Injection (NH_3 ppmv/SO_3 ppmv)	6/10	6/10	6/10	6/10	6/10	6/10	6/10	6/10	0/0	0/0	3/5	0/0	6/10	3/5	6/10	2/10

The impact of sorbent injection on the ESP performance was quantified by taking Method 17 particulate samples during each injection rate and by monitoring the arc rate in each field. The flue gas particulate concentration was measured at the ESP outlet during baseline and injection testing. During baseline testing, a Method 5 filter was used in conjunction with Method 26 measurements. During injection testing, Method 17 was employed.

Figure 3-25 shows the Unit 2 ESP outlet particulate concentrations measured during baseline and injection testing. During baseline conditions (sorbent injection rate = 0 lb/MMacf), the ESP outlet particulate concentration ranged from 0.016 to 0.026 grains/dscf at 3% O_2, with an average of 0.020 gr/dscf. For the tested carbon injection rates of 2 to 13 lb/MMacf, the measured outlet particulate concentrations were slightly below this level. These results indicate no increase in Unit 2 ESP outlet particulate concentration due to sorbent injection.

The particulate emissions from Unit 2 were consistently lower than the emissions from Unit 1 (Figure 3-3), over the course of their respective test periods. Unit 2 has a slightly lower SCA than Unit 1, but Unit 2 employs dual-flue gas conditioning. The conditioning system was employed during the collection of the test data in Figure 3-26 (except as noted on the plot). The operation of the conditioning unit did not appear to affect the Unit 2 particulate emissions.

The typical arc rate for the Unit 2 ESP is 0-1 arc/minute. According to the Plant Yates engineers, sustained arc rates greater than 10 arc/min are considered unacceptable and may damage the ESP. During the carbon injection testing, arc rates reached 10 arc/min, and in some cases exceeded this value; however, as stated above in the Unit 1 results, the two-hr carbon injection tests are not long enough to determine if higher arc rates are sustained with sorbent injection. Table 3-13 shows the spark and arc rates for the Unit 2 ESP during the baseline (no injection) testing week. Averages were taken for times in which Unit 2 was operating at greater than 95% load. Unlike Unit 1, where the first field (field 1A) experienced higher arc rates during injection, in Unit 2 the 2B and 2C fields experienced high arc rates (Figure 3-29). High spark rates, but low arc rates, are seen in the 2D and 2E fields.

Table 3-13. Spark Rate and Arc Rate of Unit 2 ESP Fields During Full (>95%) Load, Baseline Conditions

	Sparks/Minute		% of time at Full Load when Spark Rate Greater than:		Arcs/Minute		% of time at Full Load when Arc Rate Greater than:	
Field	**Average**	**St. Dev.**	**1 SPM**	**10 SPM**	**Average**	**St. Dev.**	**1 APM**	**10 APM**
2A	0.0	0.0	0%	0%	0.0	0.1	0%	0%
2B	0.0	0.1	0%	0%	14.2	14.2	68%	49%
2C	0.0	0.1	0%	0%	25.2	16.5	76%	71%
2D	31.0	16.6	80%	78%	0.0	0.3	1%	0%
2E	17.0	17.9	67%	44%	0.0	0.2	0%	0%

3.2.3 Mercury Speciation and Removal

Baseline Characterization

Baseline characterization of the mercury concentrations in the flue gas at the ESP inlet and ESP outlet locations were conducted over a three-day period on 2/25/04 through 2/27/04. During this period, semi-continuous data were collected for total vapor-phase mercury and elemental mercury (oxidized mercury calculated by difference) using three SCEM analyzers. In addition, simultaneous Ontario Hydro mercury speciation measurements were conducted at the ESP inlet and ESP outlet during full-load conditions to compare to the SCEM analyzer results. The objectives of this series of tests were: 1) to measure the native mercury concentrations at the various flue gas sample locations; 2) to measure the variability in flue gas mercury concentrations over time; and 3) to compare the performance of the SCEM analyzers with results from the Ontario Hydro standard reference method.

Table 3-14 provides a comparison of the baseline mercury measurements for the SCEM and Ontario Hydro methods. The average total and elemental mercury concentrations measured by the SCEM during the course of each two-hour Ontario Hydro run are reported. The SCEM measured ESP inlet concentrations between 5.6 and 6.5 $\mu g/Nm^3$ at 3% O_2, with an average of 6.0 $\mu g/Nm^3$. The Ontario Hydro runs measured an average 6.95 $\mu g/Nm^3$ at the ESP inlet. At the ESP outlet, the SCEM averaged 3.89 $\mu g/Nm^3$, while the Ontario Hydro runs averaged 8.22 $\mu g/Nm^3$.

Particulate mercury concentrations are not available at the ESP inlet since the ESP inlet sampling location was nestled between two sharp turns in the ductwork, making isokinetic sampling infeasible. The ESP outlet particulate mercury concentrations, as determined by the Ontario Hydro method, was less than 0.017 μg/Nm^3.

The inlet SCEM and Ontario Hydro data are within 13% of each other. However, the Ontario Hydro data indicate that the inlet stream is 75% oxidized, while the SCEM indicate 35% oxidation at the inlet. In Ontario Hydro a particulate filter is placed upstream of the impingers, allowing for intimate contact between the gas and the collected particulate matter. The SCEM method uses a self-cleaning filter in which minimizes the accumulation of particulate matter and minimizes the possibility of bias. These data indicate that the passage of flue gas through the Ontario Hydro particulate filter may have resulted in oxidation of sampled mercury. This hypothesis is further validated with the outlet data, in which the oxidation percentages of the Ontario Hydro and SCEM are in better agreement. At the ESP outlet, the flue gas had a very low particulate concentration, so that bias caused by collection of particulate on the filter was reduced. These same patterns in oxidation results were seen in the Unit 1 baseline data comparison between Ontario Hydro and SCEM.

While the inlet data show reasonable agreement between the Ontario Hydro and SCEM data, the outlet SCEM and Ontario Hydro data are not in good agreement for total mercury concentration. A mercury balance was performed around the boiler/ESP combined system. A closure of 100% indicates that the input and output values are equal. A closure less than 100% indicates that the outputs were less than the inputs. A mercury balance using ESP outlet values measured with SCEM indicates 76% closure around the boiler/ESP combination. Using the Ontario Hydro values in the mass balance (rather than SCEM data) results in 170% closure, indicating that the SCEM data are more in line with the mercury content of the coal and ash.

The discrepancies between the Ontario Hydro and SCEM at the ESP outlet are under investigation.

Sorbent Injection Tests - Darco FGD™ Carbon

Results from the Darco FGD™ injection tests were covered in the previous quarterly report.

3.2.4 Additional Data

Coal

Table 3-15 shows the analytical results for as-fired coal samples. Composite samples of the Unit 2 coal were collected twice per day downstream of the coal pulverizers and were analyzed in triplicate for mercury; an average of the triplicate analyses is reported in the table. Results from the ultimate and proximate analyses are also shown.

Fly Ash

Table 3-16 shows the results for mercury and LOI analyses of the ESP fly ash samples. Composite fly ash samples were obtained by collecting and combining ash from each field of the ESP during the baseline characterization and sorbent injection test period. The LOI results for Unit 2 are plotted alongside the Unit 1 results in Figure 3-23. For the baseline test days and the first injection test day, the Unit 2 ash LOI and mercury contents were similar to those measured on Unit 1. For the final three days of Unit 2 injection testing, the Unit 2 ash had much higher LOI and mercury contents as compared to Unit 1.

Mercury Mass Balance

A preliminary overall mass balance for mercury was estimated based on the measured concentrations of mercury in the coal, ESP fly ash, and ESP outlet gas on 3/18/04. A mass balance around the ESP was not possible because the poor sampling location at the ESP inlet precluded isokinetic particulate loading measurements. Mercury balance closure for the entire plant was 76 percent, using SCEM data for the ESP outlet. This mass balance indicates that approximately 32 percent of the mercury input with the coal was captured in the ESP fly ash.

Table 3-14. Unit 2 - Average SCEM Mercury Measurements During Baseline Characterization on 3/18/04, NH_3/SO_3 Conditioning System On

	Run No.	Sampling Period (EST)	Vapor Phase Elemental	Oxidized	Percent Oxidized	Total
			ESP Inlet, µg/Nm^3			
SCEM	1	9:15-11:15	4.37	2.16	33	6.54
OH	1		1.93	5.67	75	7.61
SCEM	2	12:15-14:15	3.88	2.11	35	5.99
OH	2		1.93	5.63	74	7.56
SCEM	3	15:40-17:40	3.65	1.95	35	5.60
OH	3		0.82	4.85	86	5.67
SCEM	Avg		3.97	2.07	34	6.04
OH	Avg		1.56	5.38	75	6.95
			ESP Outlet, µg/Nm^3			
SCEM	1	9:15-11:22	1.77	1.58	47	3.35
OH	1		5.50	3.04	36	8.54
SCEM	2	12:15-14:15	2.18	1.93	47	4.11
OH	2		4.61	2.84	36	7.45
SCEM	3	15:40-17:40	2.16	2.07	49	4.22
OH	3		5.12	3.56	41	8.68
SCEM	Avg		2.04	1.86	48	3.89
OH	Avg		5.08	3.14	37	8.22
			Removal, %			
SCEM	Avg		49	10	NA	36
OH			-226	42	NA	-18

Note: All data normalized to 3% oxygen. Vapor phase oxidized mercury for the SCEM was computed as the difference between the total and elemental measurements.

NA = Not applicable.

Table 3-15. Unit 2 - Coal Analyses for Baseline and Carbon Injection Tests

Date	3/15	3/15	3/16	3/18	3/18	3/19	3/19	3/22	3/22	3/24	3/24	3/25	3/25	3/26	3/26
Sample Time	**9:40**	**13:40**	**9:30**	**9:30**	**13:20**	**9:30**	**13:10**	**9:45**	**13:30**	**9:30**	**13:20**	**9:20**	**13:20**	**9:30**	**13:21**
Test Condition [a]	**BL**	**BL**	**BL**	**BL**	**BL**	**BL**	**BL**	**FGD**	**FGD**	**FGD**	**FGD**	**FGD**	**FGD**	**FGD**	**FGD**
Proximate, wt % as received [b]															
Moisture		5.48	5.54		5.69		6.02		5.23				5.51		5.68
Ash		10.41	11.51		11.78		11.00		11.08				11.11		10.16
Volatile Matter		29.26	28.63		27.97		28.94		28.49				29.03		29.84
Fixed Carbon		54.85	54.31		54.56		54.02		55.21				54.35		54.32
Sulfur		1.24	1.00		0.96		1.41		1.12				0.91		0.86
Ultimate, wt % as received															
Moisture	3.81										4.60				
Carbon	72.69										72.51				
Hydrogen	4.70										4.63				
Nitrogen	1.39										1.37				
Sulfur [b]	0.99										1.10				
Oxygen	5.60										5.32				
Ash	10.82										10.47				
Heating Value (Btu/lb, as received)	13136	12858[b]	12724[b]		12647[b]		12713[b]		12811[b]		13072		12754[b]		12841[b]
Mercury (µg/g, dry)		0.081	0.069		0.074		0.137		0.083		0.073		0.071		0.096
Mercury (lb/trillion Btu)		6.3	5.4		5.9		10.8		6.5		5.6		5.6		7.5
Chloride (mg/Kg, dry)					436		277		356				152		

[a] BL = baseline characterization, FGD = Darco FGD™ carbon sorbent injection;
[b] Represents Plant Yates analysis of as-bunkered fuel samples. Mercury analysis was done on separate Unit 1 as-fired coal samples.

Table 3-16. Unit 2 –ESP Fly Ash Analyses for Baseline Characterization and Sorbent Injection (SI) Tests

Date	Time	Sample Type	Test Condition	Injection Rate (lb/MMacf)	Mercury (µg/g)	LOI (%)
3/18		ESP ash	Baseline	0	0.25	7.7
3/19		ESP ash	Baseline	0	0.21	9.0
3/22	13:30	ESP ash	Darco FGD™ SI	2	0.18	6.9
3/24	13:20	ESP ash	Darco FGD™ SI	6	0.52	21.5
3/25	13:30	ESP ash	Darco FGD™ SI	2	0.40	15.2
3/26	13:30	ESP ash	Darco FGD™ SI	4	0.32	17.1

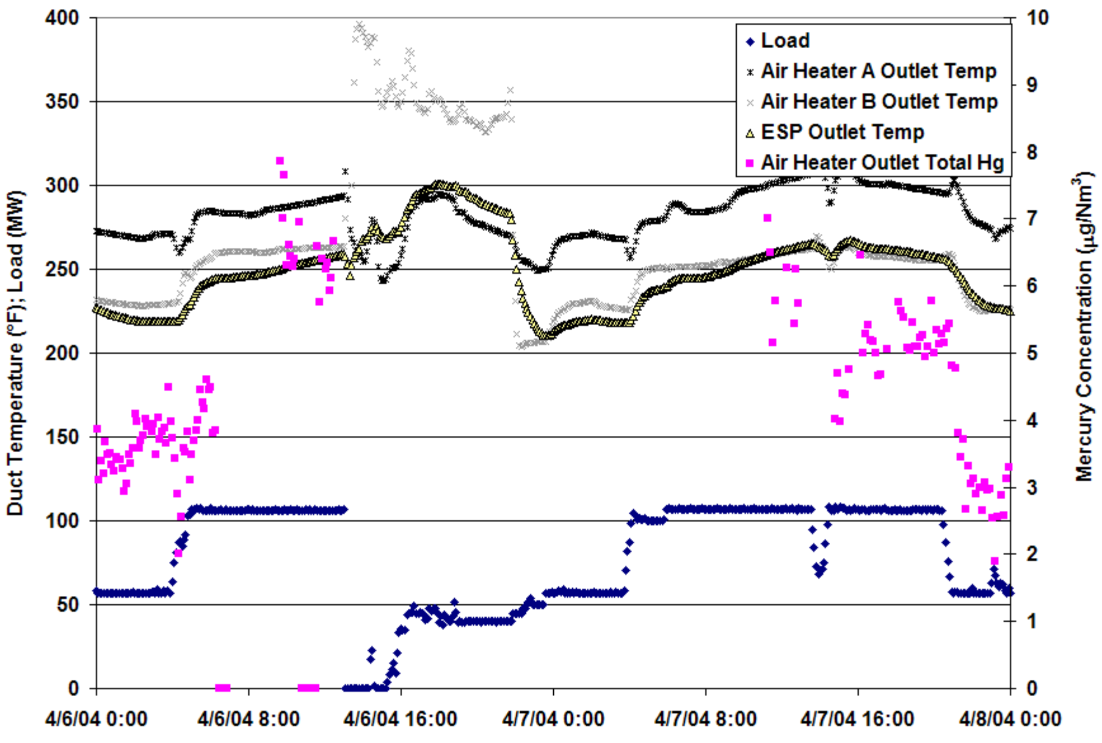

Figure 3-1. Temperature and Mercury Profile at Unit 1 Air Heater Outlet During Super HOK Testing

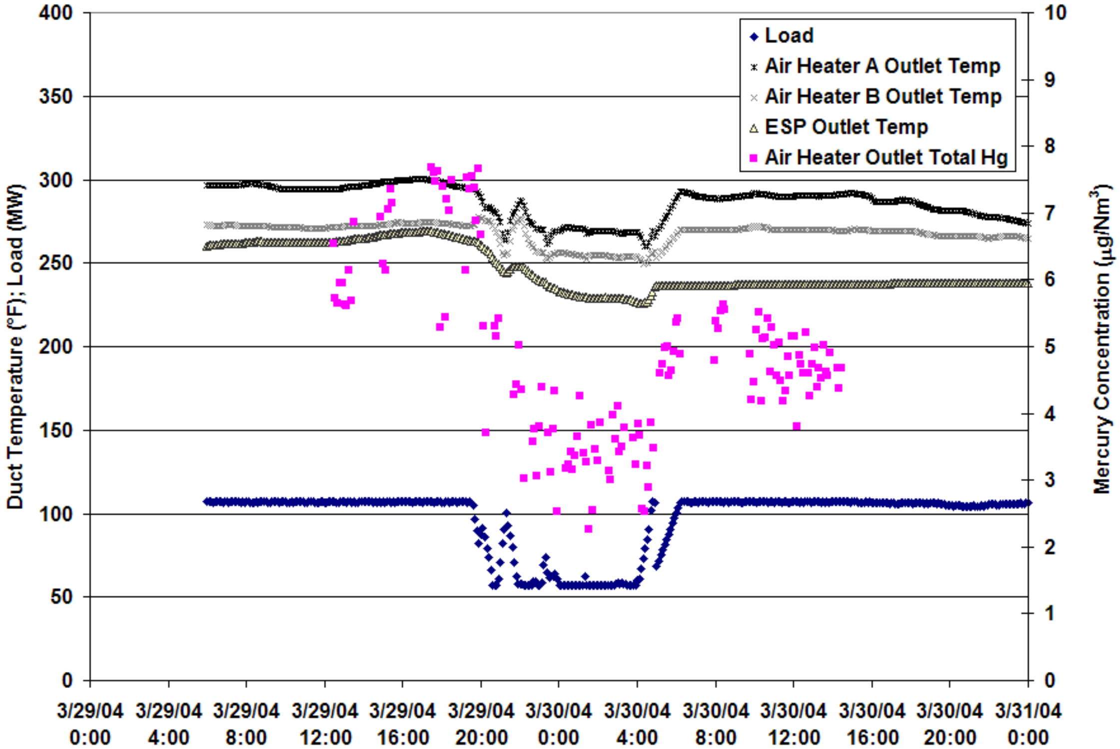

Figure 3-2. Temperature and Mercury Profile at Unit 1 Air Heater Outlet During NH Carbon Testing

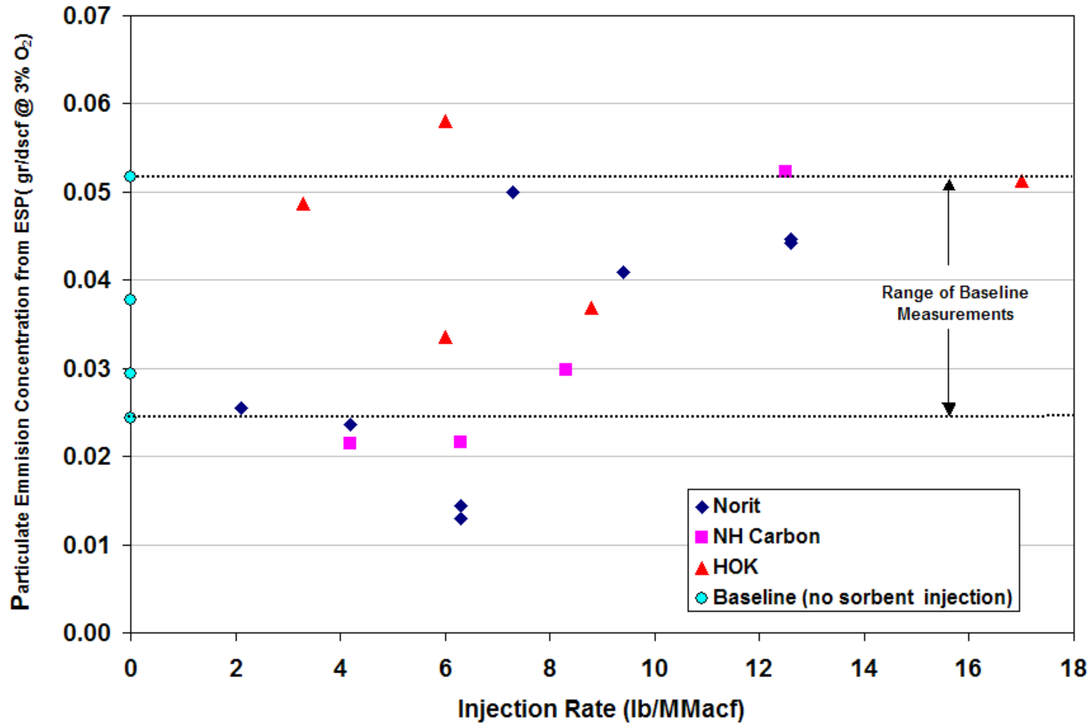

Figure 3-3. Unit 1 ESP Particulate Emissions as Measured by Method 17

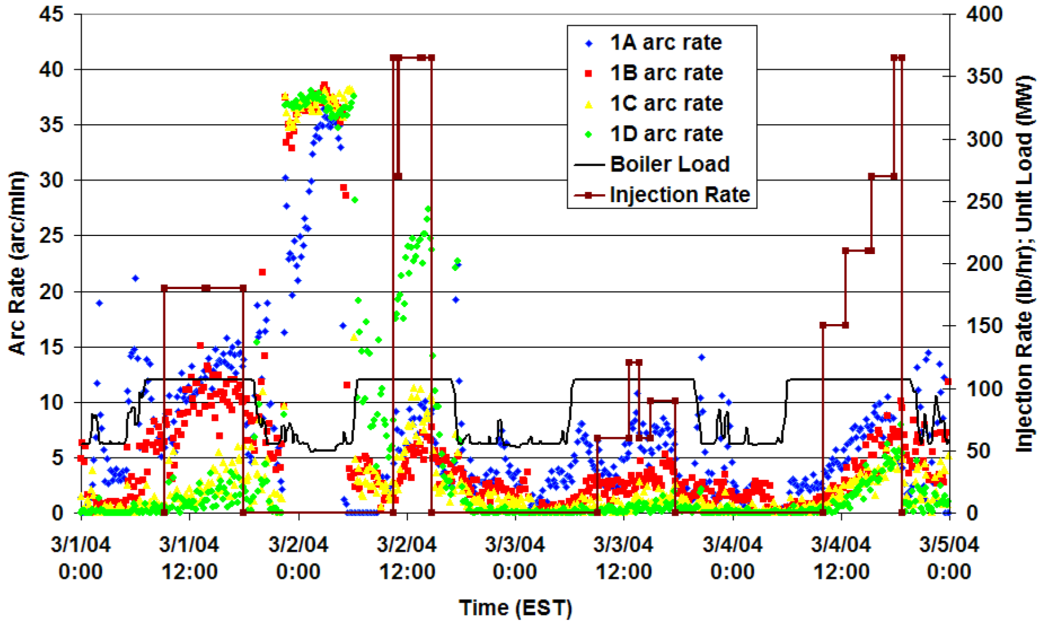

Figure 3-4. Arc Rate of Fields A, B, C, and D in the Unit 1 ESP During Injection of Darco FGD™

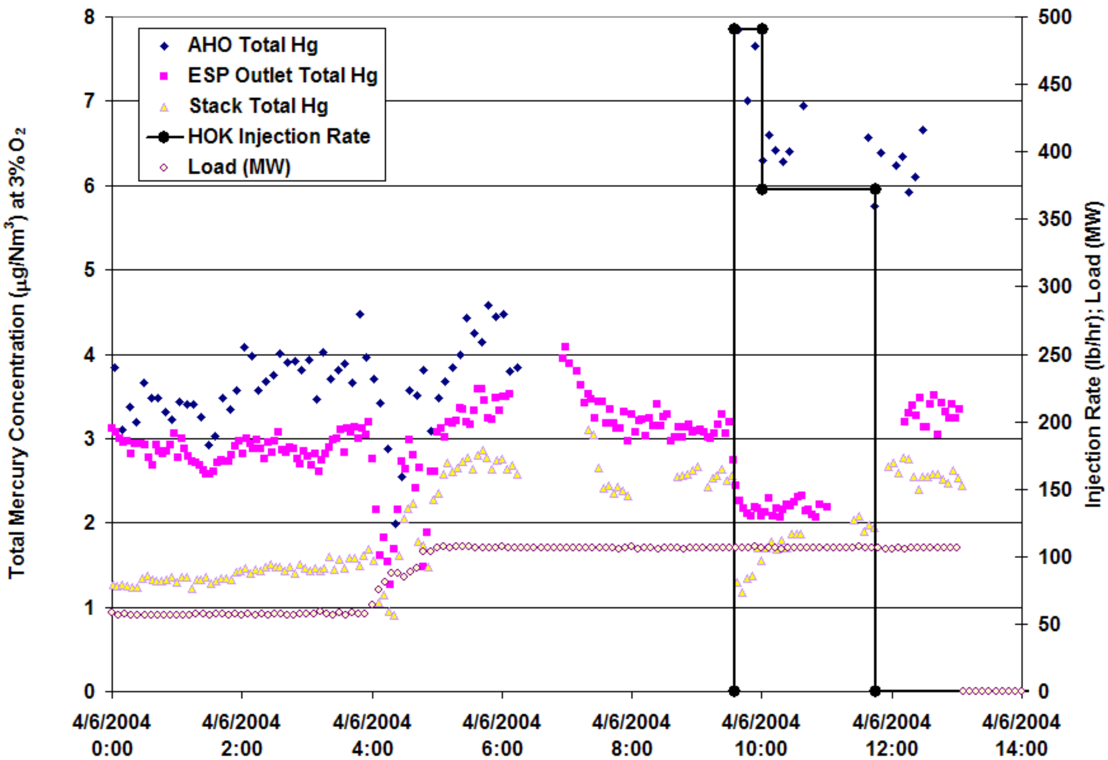

Figure 3-5. Vapor Phase Mercury Concentrations Measured at Air Heater Outlet, ESP Outlet, and Stack During Day 1 of Super HOK Injection Testing

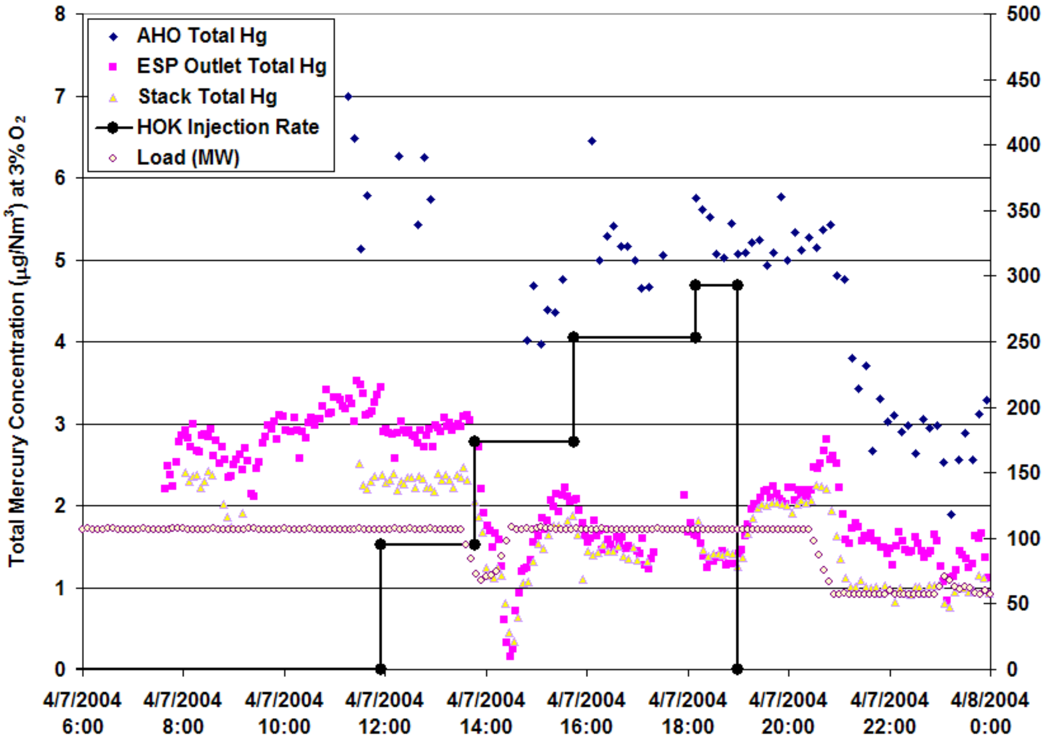

Figure 3-6. Vapor Phase Mercury Concentrations Measured at Air Heater Outlet, ESP Outlet, and Stack During Day 2 of Super HOK Injection Testing

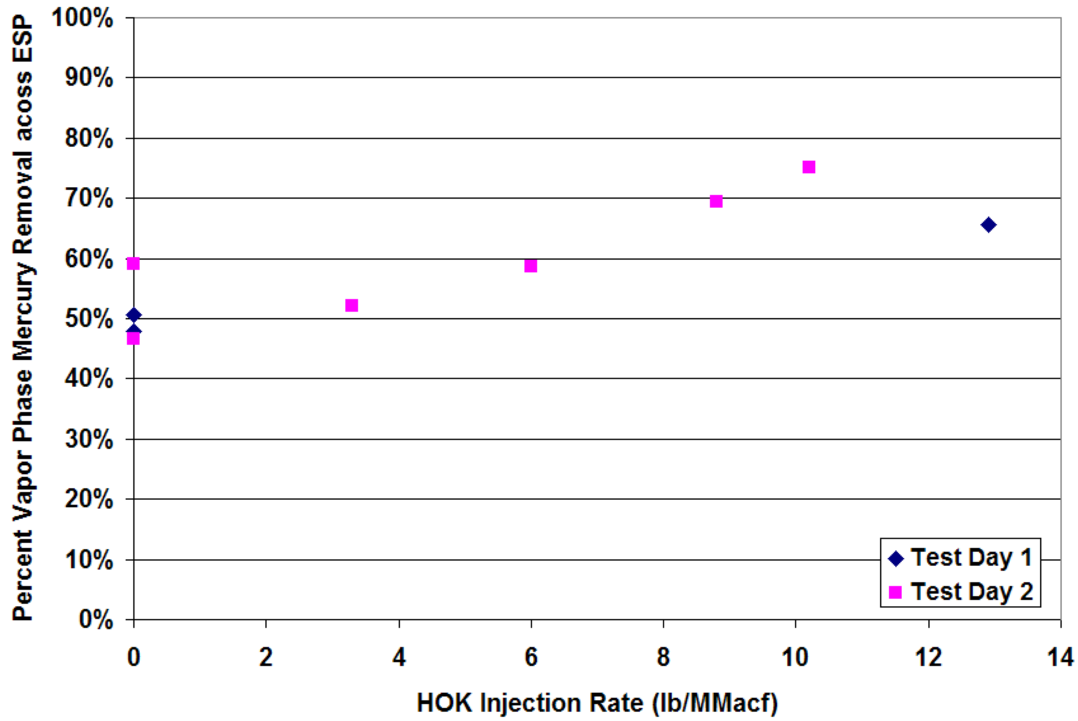

Figure 3-7. Percent Removal of Total Mercury Across Unit 1 ESP as a Function of Super HOK Injection Rate

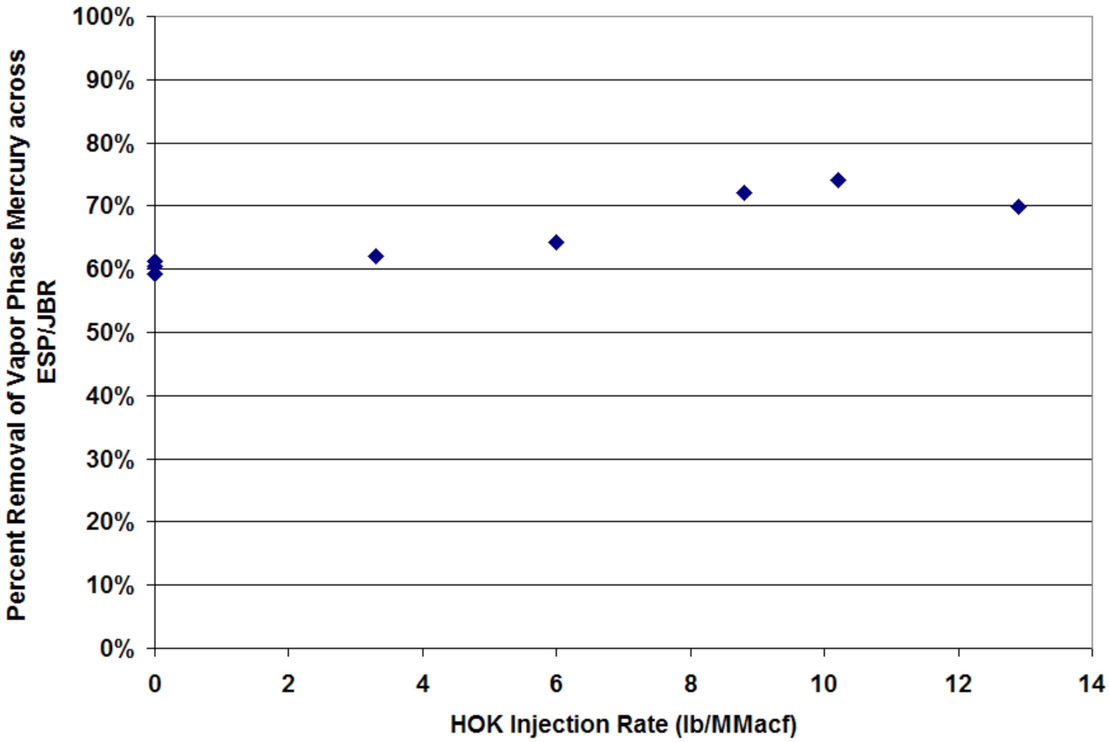

Figure 3-8. Percent Removal of Total Mercury Across Unit 1 Combined ESP/JBR as a Function of Super HOK Injection Rate

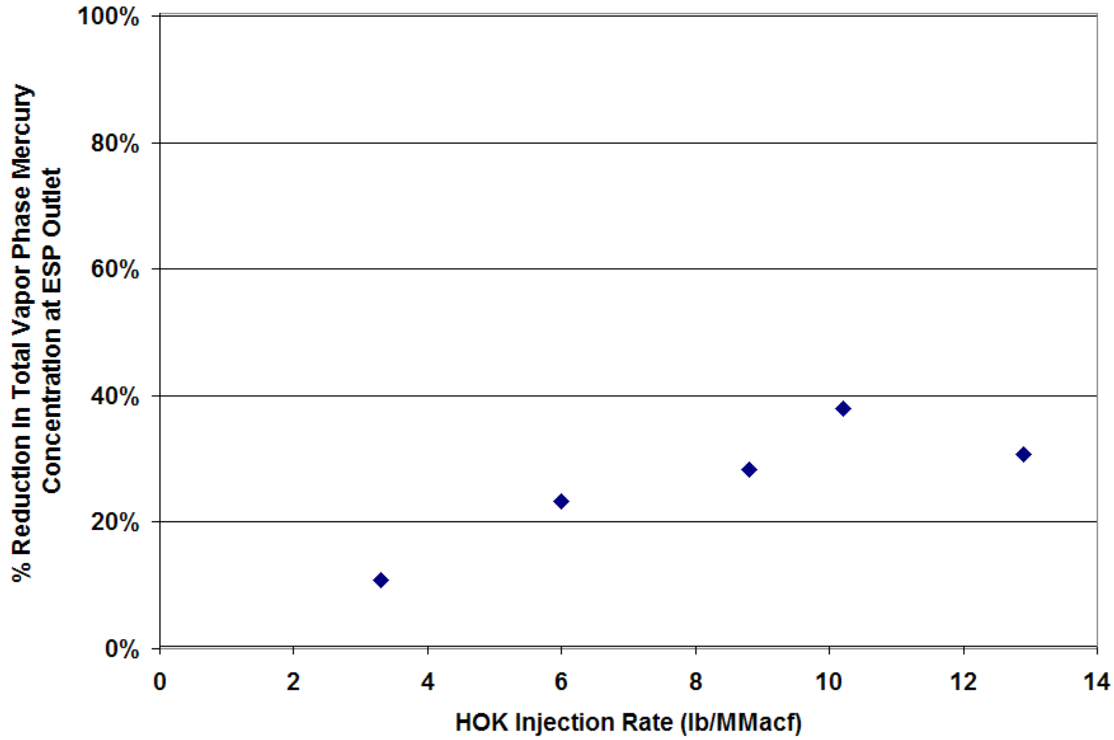

Figure 3-9. Unit 1 - Percent Reduction in Total Vapor-Phase Mercury Concentration at the ESP Outlet Relative to Baseline During Super HOK Carbon Injection

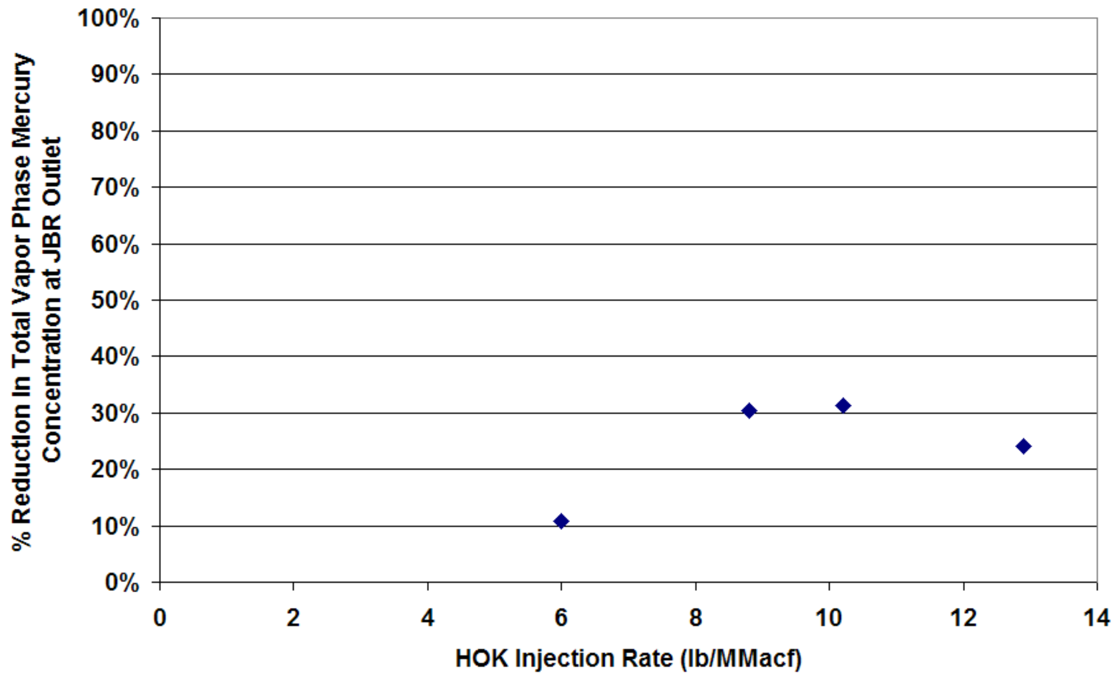

Figure 3-10. Unit 1 - Percent Reduction in Total Vapor-Phase Mercury Concentration at the JBR Outlet Relative to Baseline During Super HOK Carbon Injection

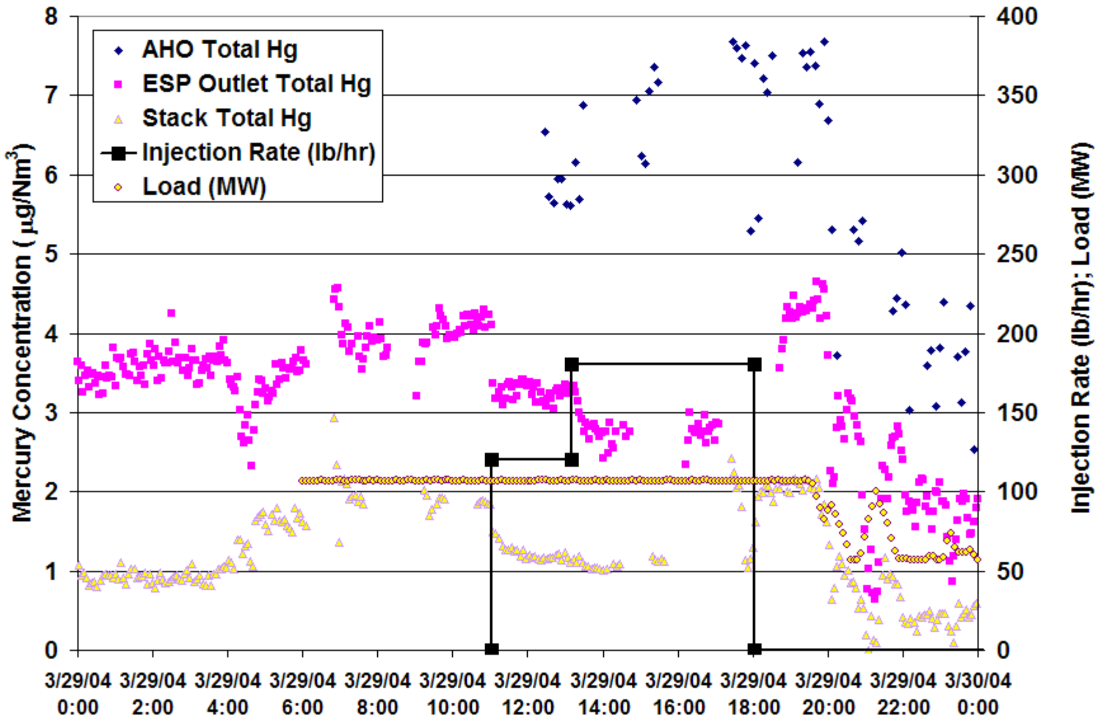

Figure 3-11. Vapor Phase Mercury Concentrations Measured at Air Heater Outlet, ESP Outlet, and Stack During Day 1 of NH Carbon Injection Testing

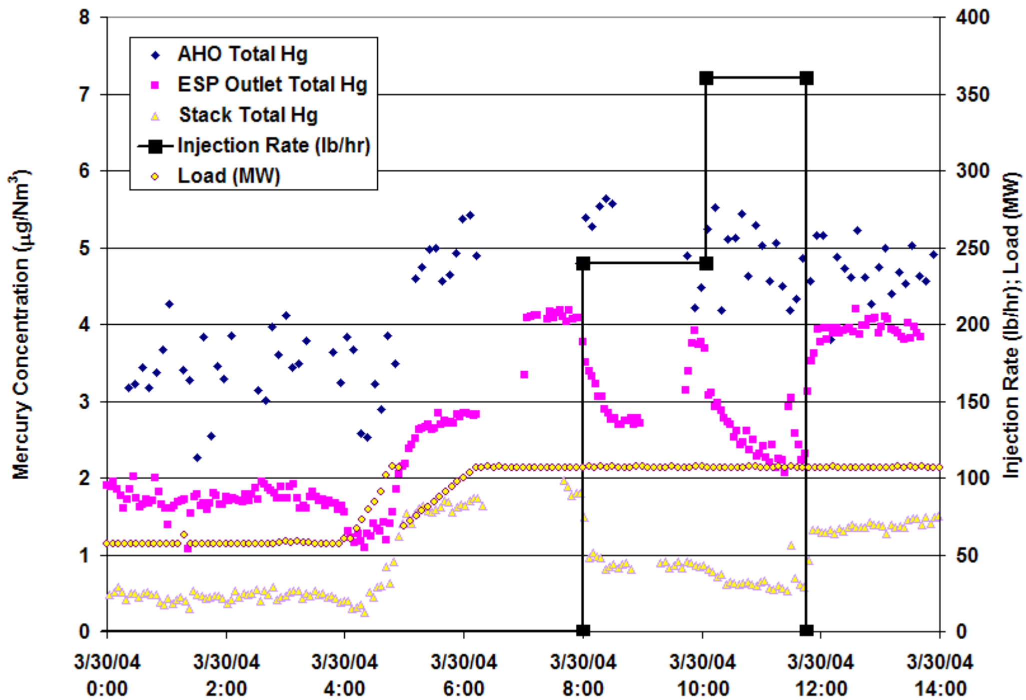

Figure 3-12. Vapor Phase Mercury Concentrations Measured at Air Heater Outlet, ESP Outlet, and Stack During Day 2 of NH Carbon Injection Testing

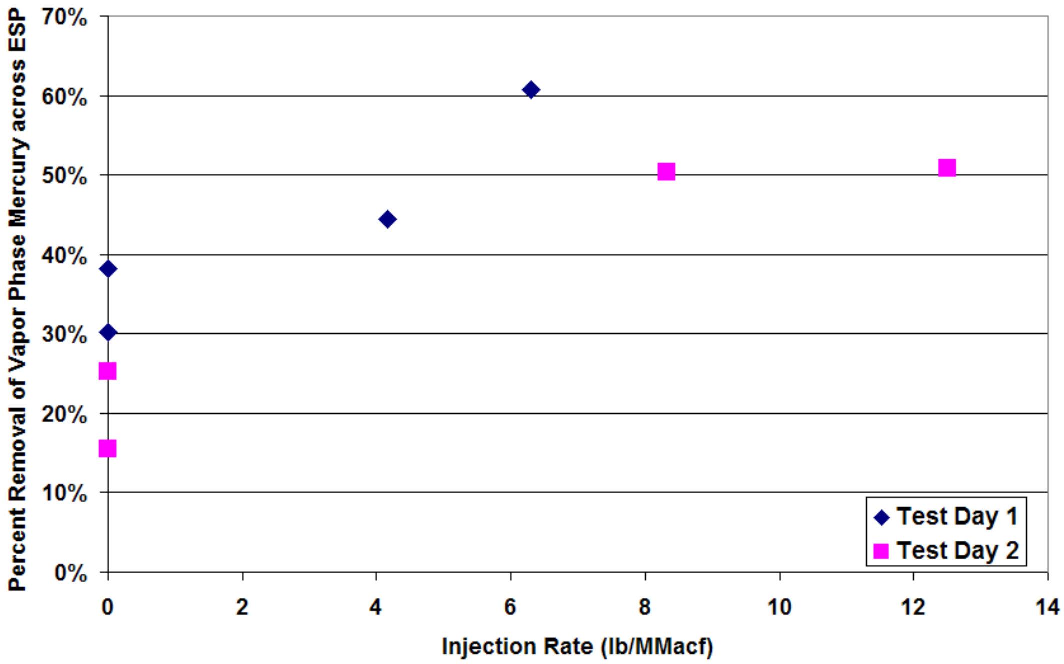

Figure 3-13. Percent Removal of Total Mercury Across Unit 1 ESP versus NH Carbon Injection Rate

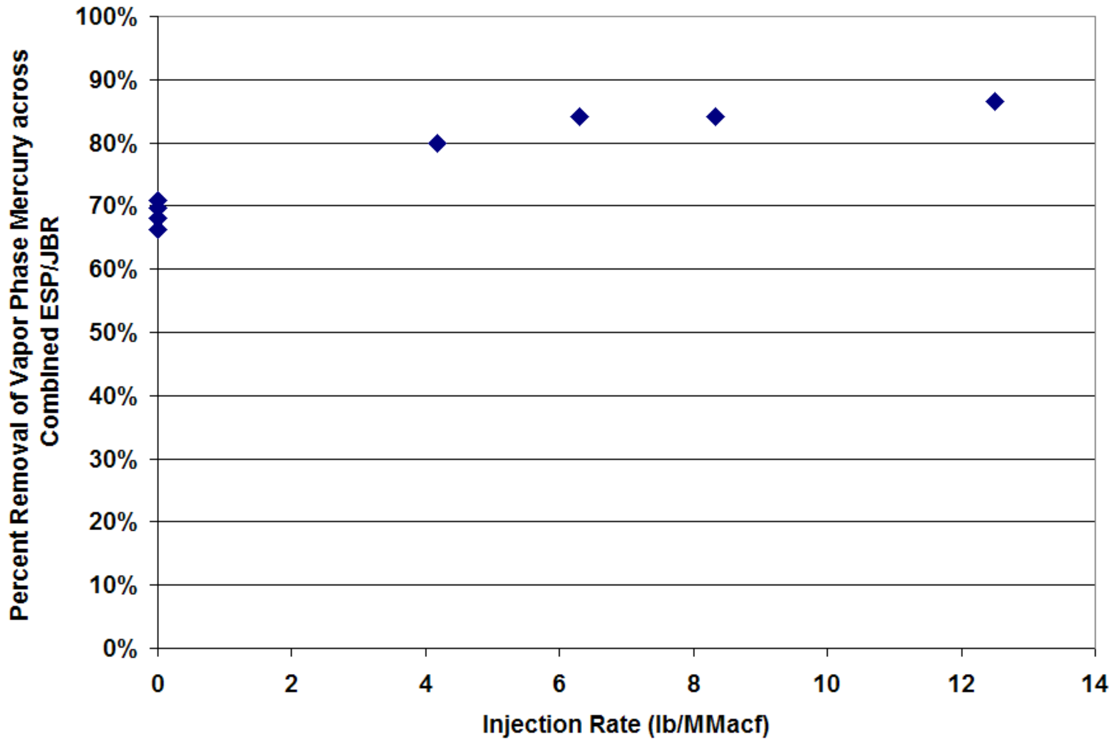

Figure 3-14. Percent Removal of Total Mercury Across Unit 1 Combined ESP/JBR versus NH Carbon Injection Rate

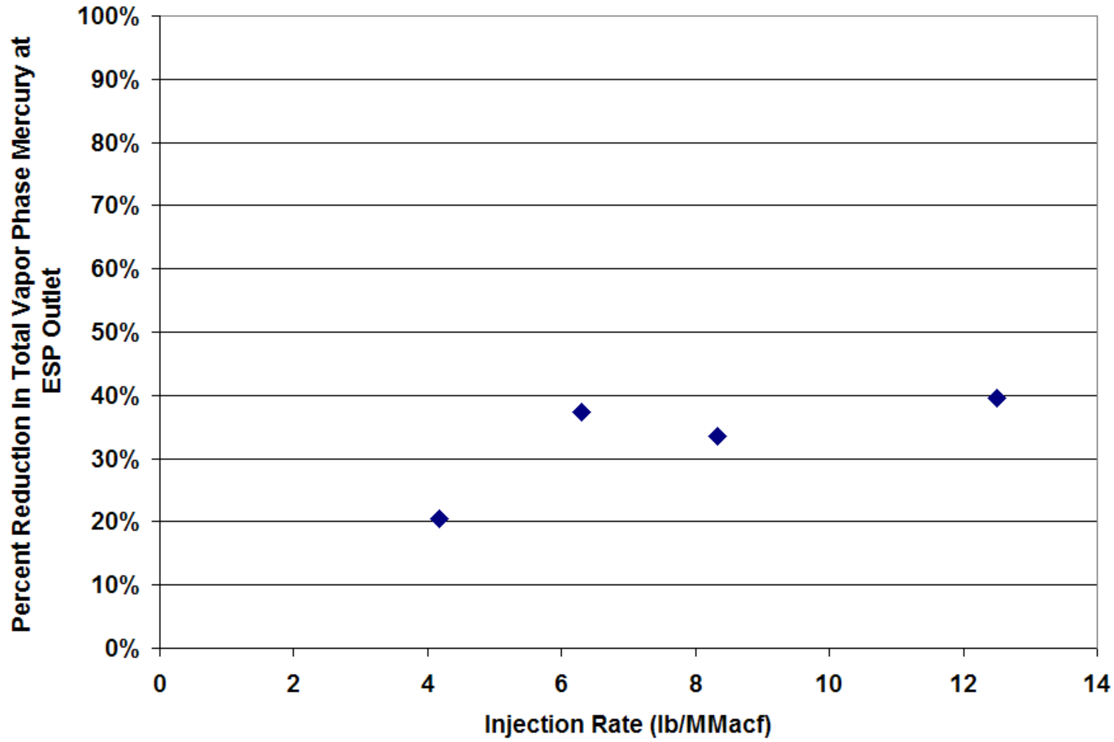

Figure 3-15. Unit 1 - Percent Reduction in Total Vapor-Phase Mercury Concentration at the ESP Outlet Relative to Baseline During NH Carbon Injection

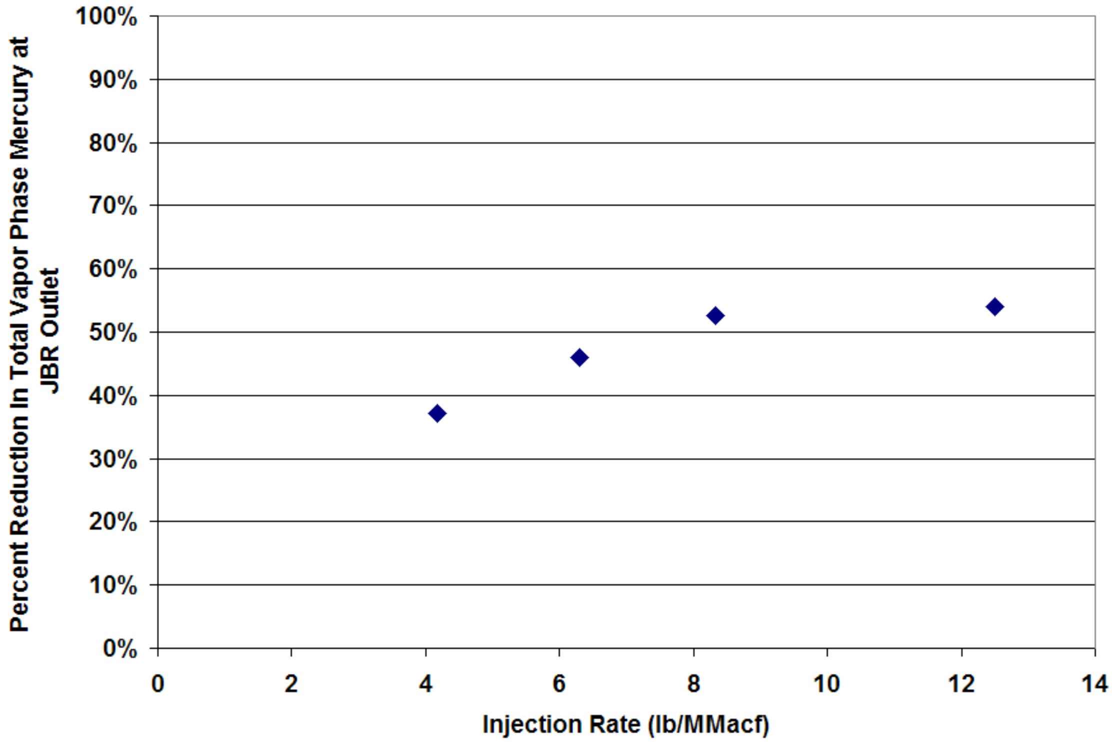

Figure 3-16. Unit 1 - Percent Reduction in Total Vapor-Phase Mercury Concentration at the JBR Outlet Relative to Baseline During NH Carbon Injection

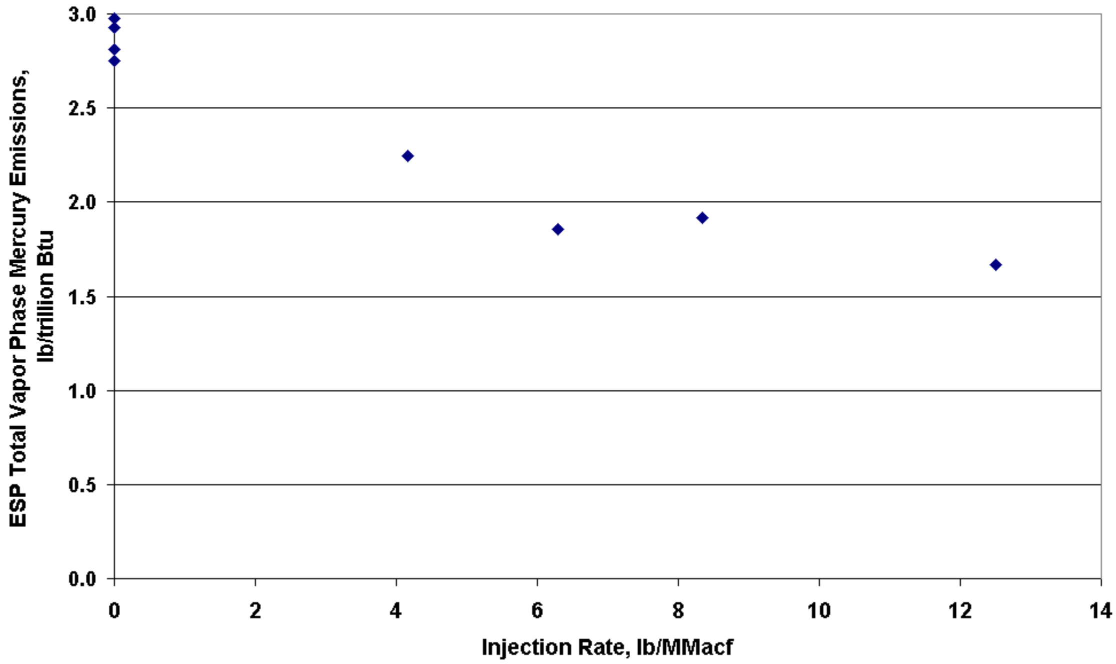

Figure 3-17. Unit 1 – ESP Total Vapor Phase Mercury Emissions as a function of NH Carbon Injection Rate

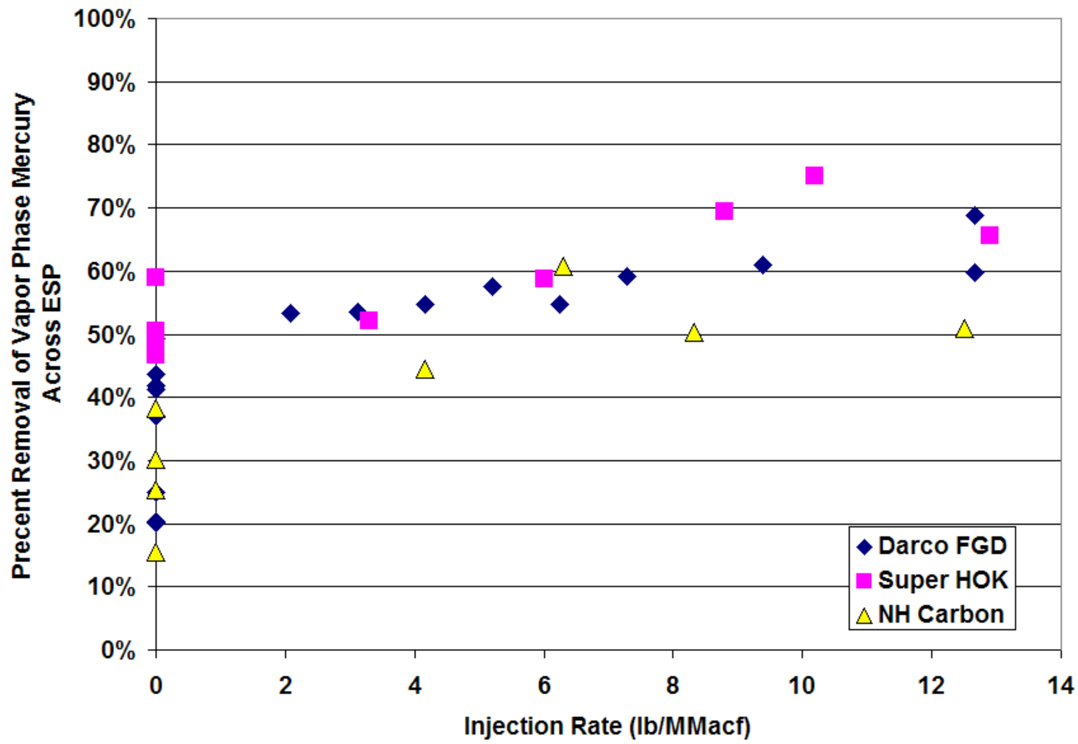

Figure 3-18. Comparison of Mercury Removal Efficiency Across the ESP of the Three Sorbents Tested on Unit 1

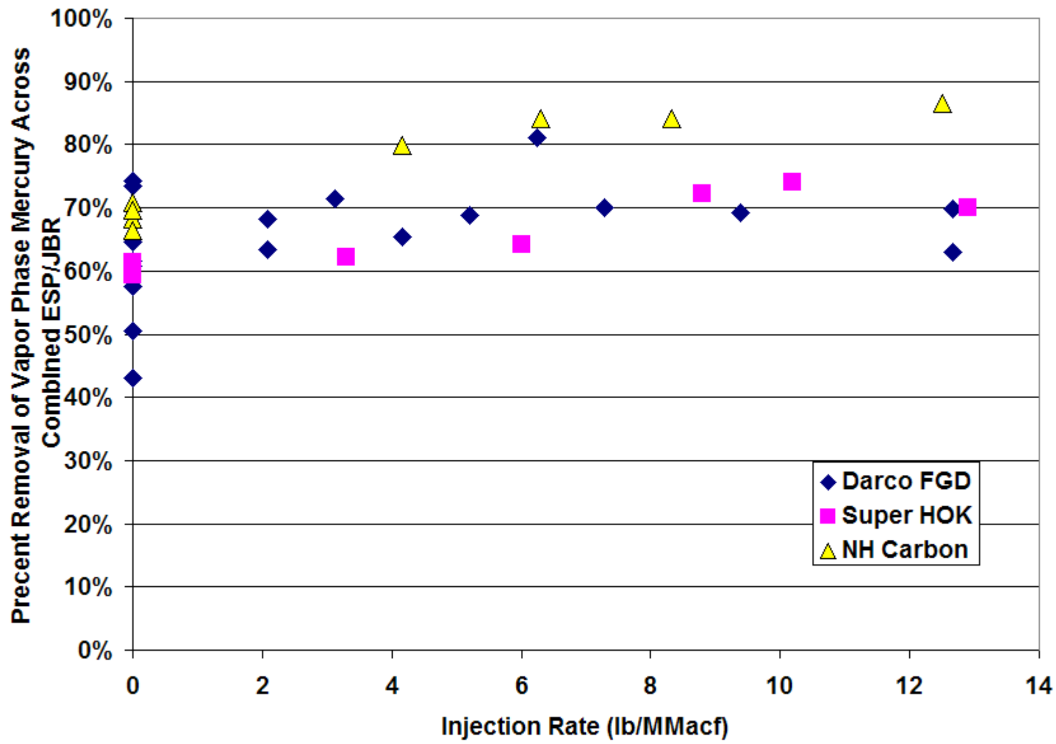

Figure 3-19. Comparison of Mercury Removal Efficiency Across the Combined ESP/JBR of the Three Sorbents Tested on Unit 1

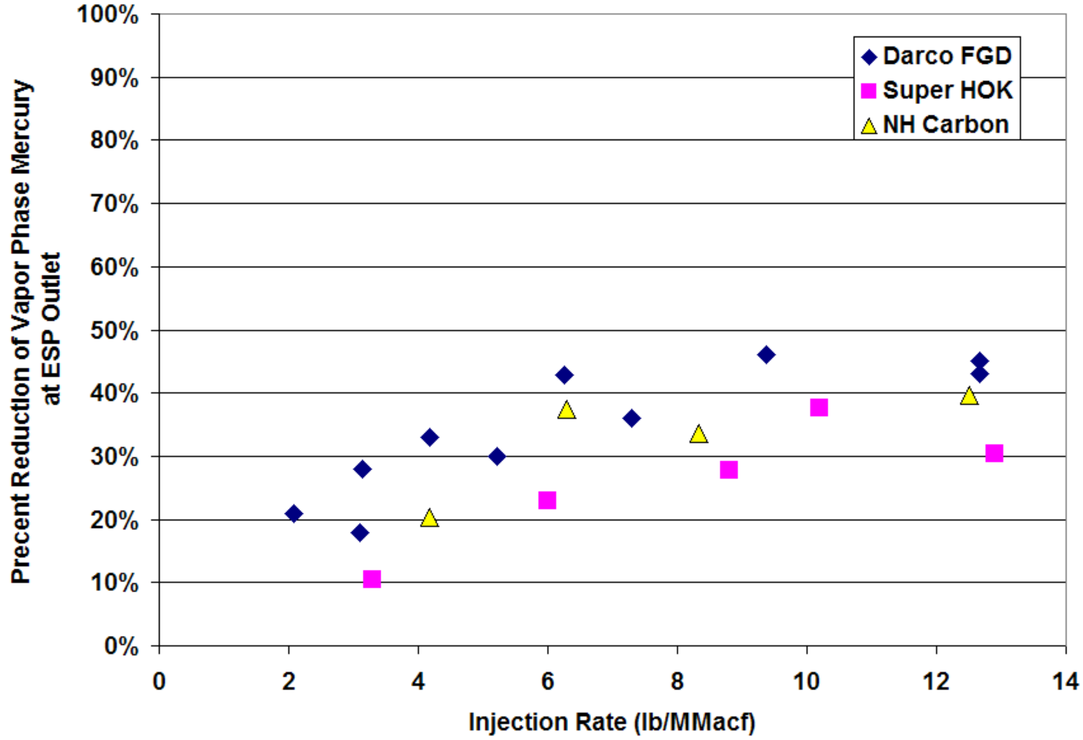

Figure 3-20. Comparison of Mercury Reduction at the ESP Outlet for the Three Sorbents Tested on Unit 1

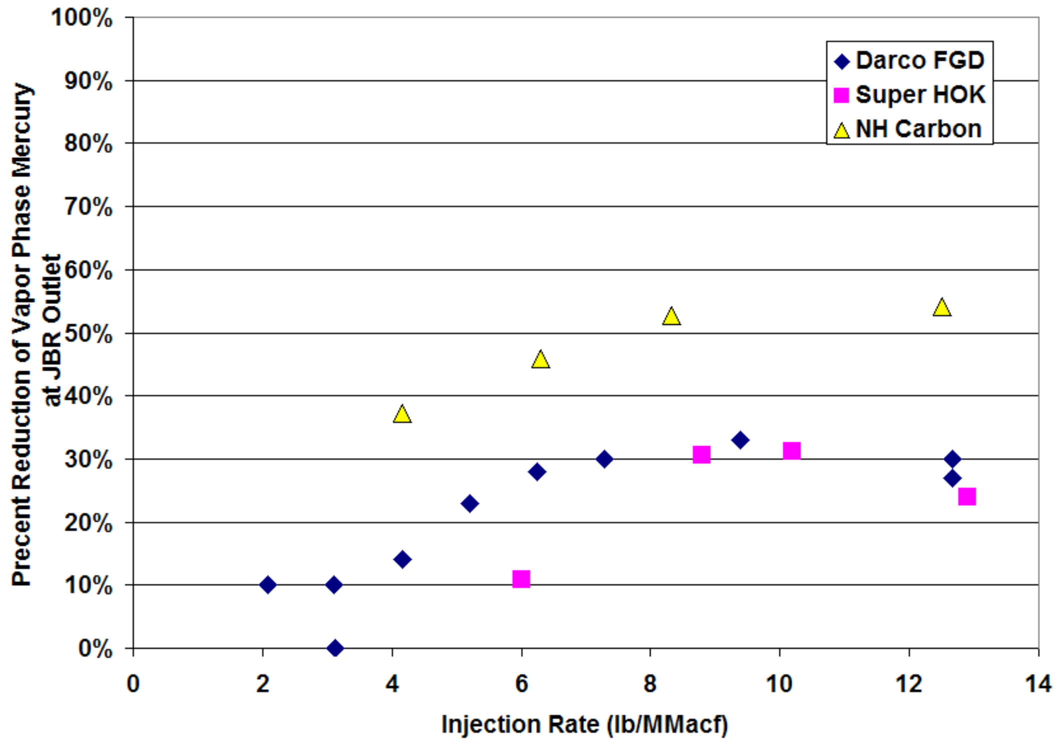

Figure 3-21. Comparison of Mercury Reduction at the JBR Outlet for the Three Sorbents Tested on Unit 1

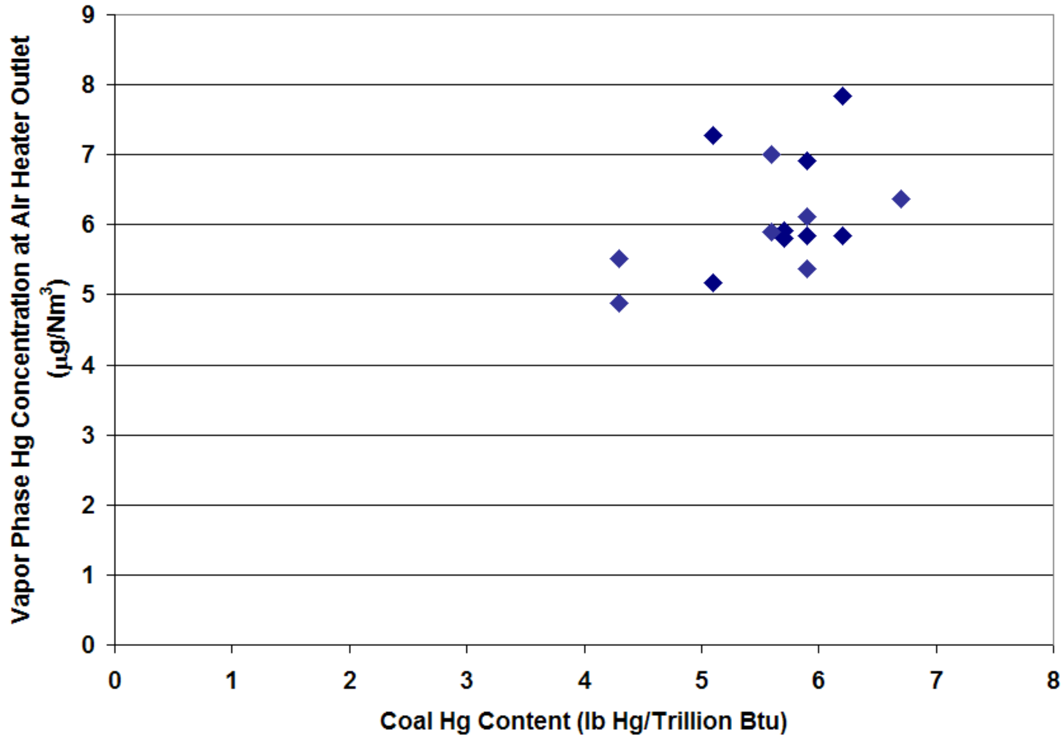

Figure 3-22. Air Heater Outlet Vapor Phase Mercury Concentration as a Function of Coal Mercury Content

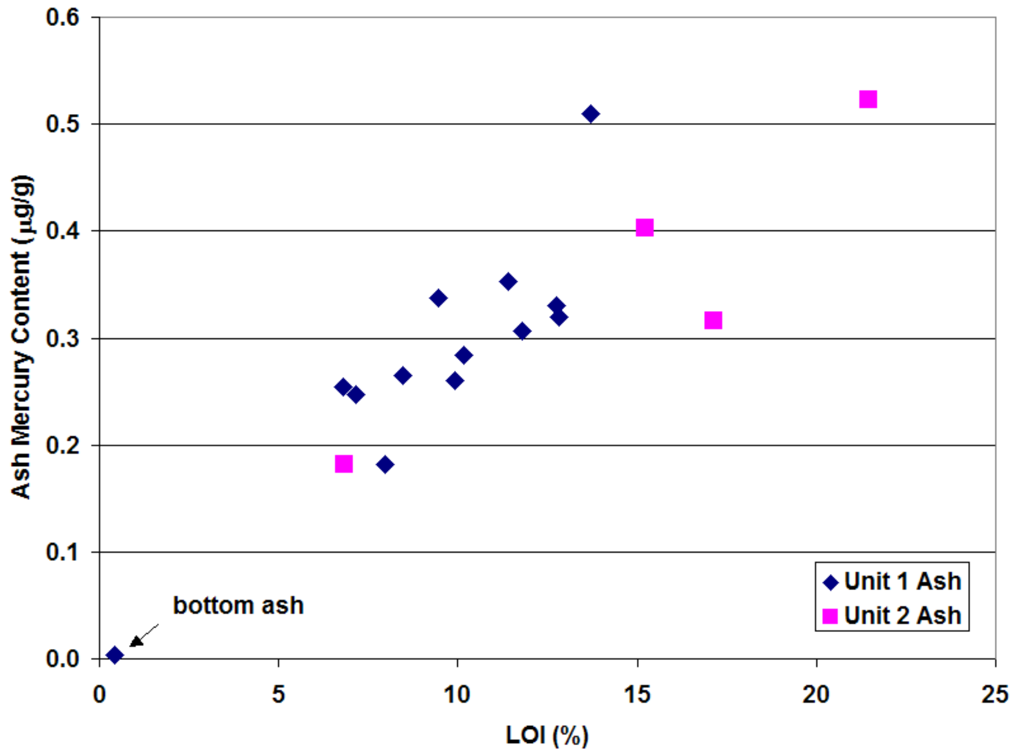

Figure 3-23. Ash Mercury Content as a Function of the Ash LOI Content

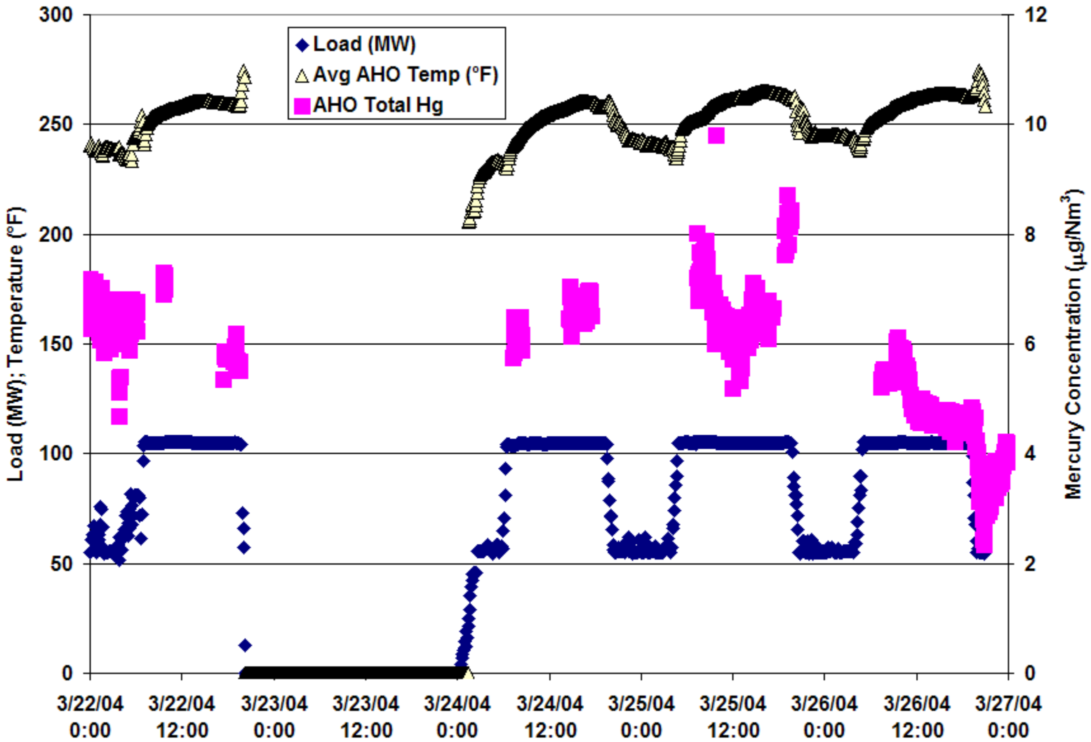

Figure 3-24. Unit 2 Air Heater Outlet Temperature and Mercury Concentration Profile During Darco FGD™ Testing

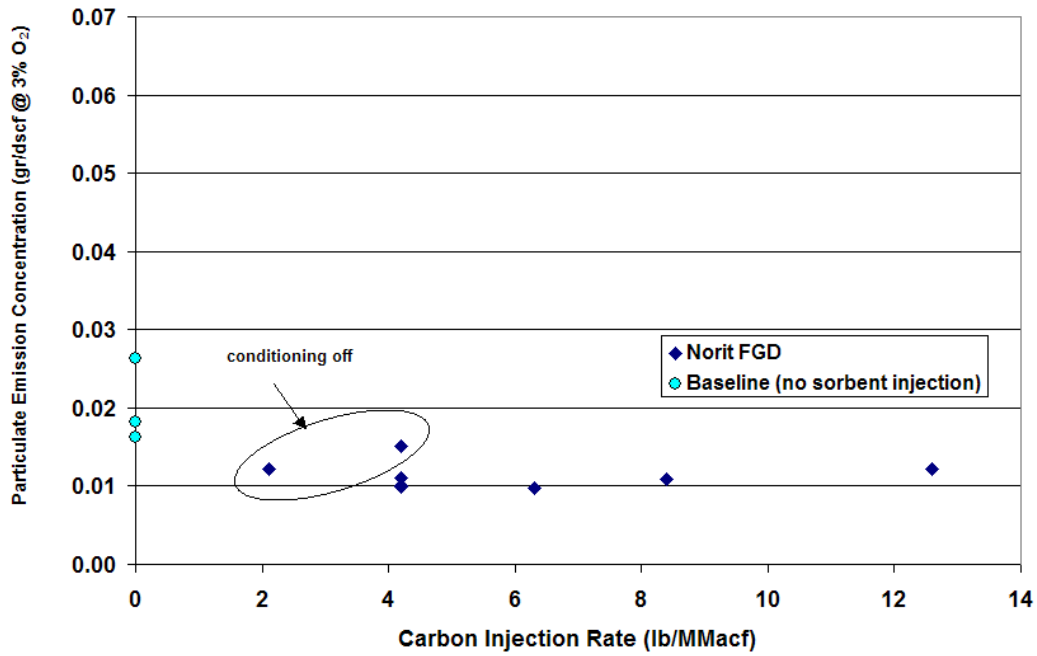

Figure 3-25. Unit 2 Particulate Emissions as Measured by Method 17

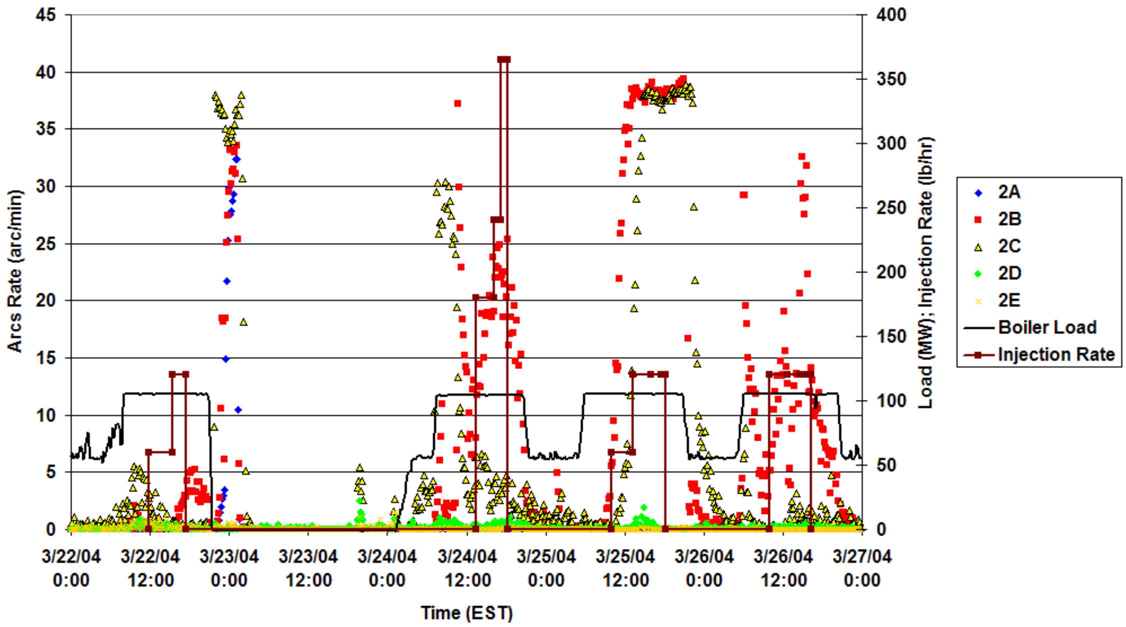

Figure 3-26. Arc Rates for Individual Fields in Unit 2 ESP during Darco FGD™ Injection Testing

4.0 Conclusions

Currently available results from tests conducted during this quarter support the following conclusions:

Unit 1 ESP and JBR FGD System

- Native removal of total vapor-phase mercury across the Unit 1 ESP ranged from 25 to 50 percent during the various baseline measurement test periods.
- Injection of the benchmark Darco FGD™ activated carbon upstream of the Unit 1 ESP (SCA = 173 ft^2/1000 acfm) resulted in total vapor-phase mercury removals across the ESP ranging from 50 to 70 percent at injection rates ranging from 2.3 to 12.7 lb/Mmacf (this removal percentage includes native mercury removal). Similar results were seen for the other two tested carbons, Super HOK and NH carbon.
- Injection of activated carbon upstream of the Unit 1 ESP resulted in a significant increase in the arc rate in all fields of the ESP. Arc rates increased with increasing sorbent injection rate. Arc rates of 10 acr/minute and higher were observed during the carbon injection tests.
- The mercury content of the Unit 1 ESP fly ash increased with increasing LOI during both baseline and Darco FGD™ carbon injection tests. LOI in the ESP ash ranged from 7 to 13% during the baseline and carbon sorbent injection tests.
- For the combined ESP/JBR FGD system, removal of total vapor-phase mercury leveled off at approximately 70-80 percent at an injection rate of approximately 3 lb/MMacf and little additional removal of total mercury was observed at higher injection rates.
- Injection of activated carbon did not appear to increase the particulate emissions from the Unit 1 ESP.

Unit 2 Dual Conditioning ESP System

- The use of the dual flue gas conditioning system on Unit 2 had no impact on the ability of Darco FGD™ carbon to remove vapor-phase mercury across the ESP.
- Injection of activated carbon did not appear to increase the particulate emissions from the Unit 2 ESP.

5.0 Activities Scheduled for Next Quarter

The next quarterly reporting period covers the period July 1, 2004 through September 30, 2004. The primary activities planned for this period include continued data evaluation for the Unit 1 and Unit 2 parametric tests, preparation of the site test report for all of the parametric tests conducted on Units 1 and 2, and selection of the appropriate sorbent injection rate(s) to be used during the Unit 1 long-term test phase. An in-depth analysis of the arcing problem with the ESPs is planned. Development of a plan to study the effects of arcing on the ESP with carbon injection during long-term tests is also underway.

6.0 References

None for this document.